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Science

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Biology

How We Move
The Gross Anatomy of Motion

Course Guidebook

Elizabeth A. Murray

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Elizabeth A. Murray is an award-winning professor and forensic anthropologist. She received her PhD in Interdisciplinary Studies in Human Biology from the University of Cincinnati. She primarily teaches graduate-level gross anatomy for future health care professionals. She has also served as an instructor for organizations such as the National Institute of Justice and the International Association of Coroners & Medical Examiners. *Kirkus Reviews* listed her book *The Dozier School for Boys: Forensics, Survivors, and a Painful Past* as one of the best young adult books of 2019.

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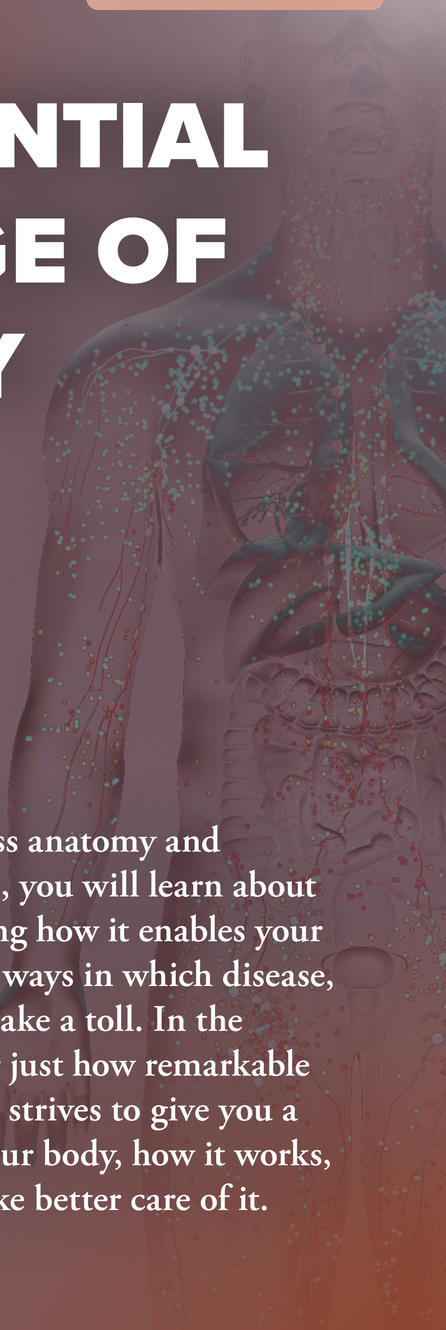
Lecture 1

THE ESSENTIAL LANGUAGE OF ANATOMY



This course focuses on gross anatomy and movement. In this course, you will learn about the human body, including how it enables your routine activities and the ways in which disease, disorder, and injury can take a toll. In the process, you will discover just how remarkable your body is. This course strives to give you a greater appreciation of your body, how it works, and even how you can take better care of it.

Gross Anatomy

While gross anatomy can often be gross—in the typical use of that term, especially during dissection or in the morgue—gross anatomy refers to the structures that we can see with the naked or unaided eye. So, this course will not focus on cells and other microscopic components of human anatomy; instead, it'll focus on bones, muscles, and nerves. In addition, it'll cover the physiology of movement to better understand the relationships of structure and function, such as at the joints of the body.

Another thing makes gross anatomy different from typical anatomy and physiology courses is that gross anatomy uses a regional approach. If you've had anatomy and physiology before, you probably studied it by systems: the skeletal system, nervous system, digestive system, reproductive system, and so forth.

But gross anatomy examines a particular region of the body—such as the back, thigh, abdomen, or hand—and integrates the bones, muscles, nerves, blood vessels, and other structures or organs in that given body region. So in this sense, gross anatomy is far more integrative as compared to systemic anatomy, in which body systems are covered but not usually combined as a whole within a region.

With that said, ultimately, gross anatomy requires the regions studied to be put together for a full understanding of the body relationships. This includes the interactions between regions and the overall pathways of structures that travel from one region to another—such as blood vessel or nerve pathways. But the regions are studied first.

Anatomical Terminology

Learning anatomical terminology is quite literally learning more about ourselves and, in combination with other medical terminology, makes us more informed patients, caregivers, workout partners, and sports enthusiasts.

Let's start with standard anatomical position, which means standing up and facing forward with your feet slightly apart and your palms facing front. This universally fixes the body in space to provide a common frame of reference, regardless of the various positions you can move your body into. This anatomical position allows you to apply directional terms that never change, whether you are standing up, lying down, or even standing on your head.

The importance of the palms facing forward was decided long ago in the study of anatomy. In this position, the two bones of the forearm—the radius and the ulna—are parallel from elbow to wrist. When you turn your palms to face backward, the radius crosses over the ulna like an *X*. You can feel this if you put your hand around your opposite forearm and rotate that palm—a movement that, by the way, happens at the elbow, not at the wrist.

To reinforce what you learn in this course, you can look at photos of body builders and dancers and label muscles and bony landmarks—and look at your own body, too. Another tool you can use is palpation: to examine by touch. In some cases, you can palpate bones and muscles on your own body, or on that of a partner.

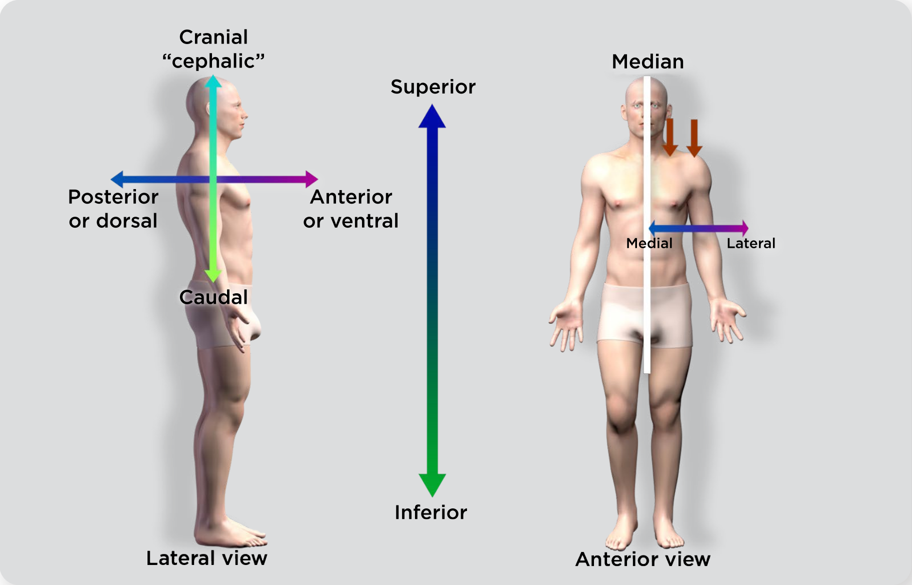
From the standard position, anatomy uses specific terms to express body directionality. For example, *superior* means "up," away from the pull of gravity, so in humans, that's the head end. *Inferior* means "down," toward the pull of gravity, or toward the ground. *Anterior* means "forward," or in the direction that you move, while *posterior* means "backward," or opposite the direction of your typical movement.

Those four terms—*superior*, *inferior*, *anterior*, and *posterior*—all relate to the space around you in which you navigate. There are also equivalent directional terms that relate to parts of the body. *Cranial*—or *cephalic* in some references—means "the head end," and *caudal* means "toward the tail end." So, considering that, *superior* is equivalent to *cranial*, and *caudal* means the same thing as *inferior*. And while you might say, "Well, I don't have a tail," you did as an embryo. What's more, *cranial* and *caudal* are usually used to refer to the head and trunk of the body—of course, you're not an elephant, but you know where your "trunk" is.

There are also body part terms that are equivalent to *anterior* and *posterior*. You've probably heard of *dorsal* related to the dorsal fin on a shark; the dorsal side is the spine side in animals with a backbone. So, with regard to *anterior* or *posterior*, the anatomical equivalent of *dorsal* is *posterior*. Since *posterior* means "opposite the direction of movement," its body part equivalent is the dorsal side of the body. And *anterior* is the same as the *ventral* side of the human body—that's in the direction you typically navigate.

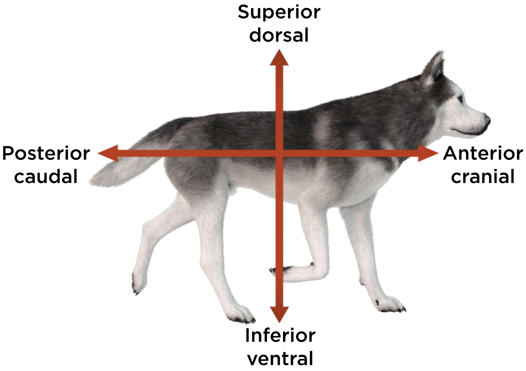
The ventral side of the torso can also be called the belly side. While most people think *belly* is just a cute word that might refer to a baby's belly, it's a perfectly adequate anatomical term for the side of the body opposite the spine. So, in humans, *ventral* equals *anterior*—but *ventral* relates to the body itself, while *anterior* means "in the direction an animal moves."

Other anatomical terms you need to be familiar with for this course include *medial* and *lateral*. *Medial* means "closer to the midline of the body," and *lateral* means "toward the side of the body." For example, when comparing the clavicle to the shoulder, the shoulder is lateral. In that comparison, the clavicle is also said to be medial to the shoulder—the terms switch depending on the context.



Anterior, which means “in the direction of movement,” does not equal *ventral* in your dog or cat. Instead, *anterior* equals *cranial* in a four-legged creature, since its head is the same direction in which it moves. *Posterior*, then, equals *caudal*—your dog or cat’s tail end.

The equivalent of *ventral* in a dog or cat is *inferior*. *Dorsal*, as the spine side, is *superior* in a four-legged animal.



But if you compare the clavicle to the sternum, then the clavicle is lateral, and the sternum is medial—the relationships change depending on which two structures are being compared. In fact, the sternum could be said to be *median*, which refers to being on the midline of the body.

But other than median structures, since there is only one midline, it’s all about comparison. These directional terms are used to compare structures to each other, and the relationships change depending on what’s being compared.

Additionally, the term *intermediate* can be used to indicate that something is between two structures. For example, the clavicle is intermediate when compared to the sternum and shoulder.

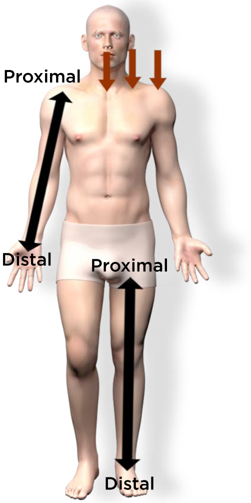
Two other terms related to the sides of the body are *ipsilateral*, which means “on the same side of the body,” and *contralateral*, which means “on opposite sides of the body.” These terms are used when talking about body movements, such as when a muscle on the right side of the body causes movement to the left.

Another instance in which *intermediate* comes in handy is when talking about depths in the body. *Superficial* means "closer to the body's surface," *deep* means "farther from the body's surface," and *intermediate* could refer to a structure between those. If you compare the skin to the muscles, the skin is superficial and the muscles are deep, but if you compare the muscles to the bones, the muscles become superficial, and the bones are deep. If you compare all three of those, the skin is superficial, the muscles are intermediate, and the bones are deep.*

Also, these terms relate, in some degree, to how we approach a body in the lab, or perhaps in a physical exam or during surgery. It's as if the body has a cylindrical core down its middle. If the body is faceup, which in forensics and anatomy is called supine, the sternum is superficial, and the heart is deep to that. If the body is facedown, or prone, the ribs would be superficial, and the kidneys would be deep to them.

Proximal and *distal* are directional terms that relate to the limbs. *Proximal* means "closer to the origin of a structure," such as a limb, while *distal* means "farther away from the structure's origin." So, when comparing the shoulder to the elbow, the shoulder is proximal, and the elbow is distal. But when comparing the elbow to the wrist, the elbow is proximal, and the wrist is distal to it.†

When referencing a limb, you don't use *superior* and *inferior*; you use *proximal* and *distal*. With that said, *medial* and *lateral* still apply. So if you're in standard anatomical position, your thumb is lateral, and your little finger is medial.



Anterior view

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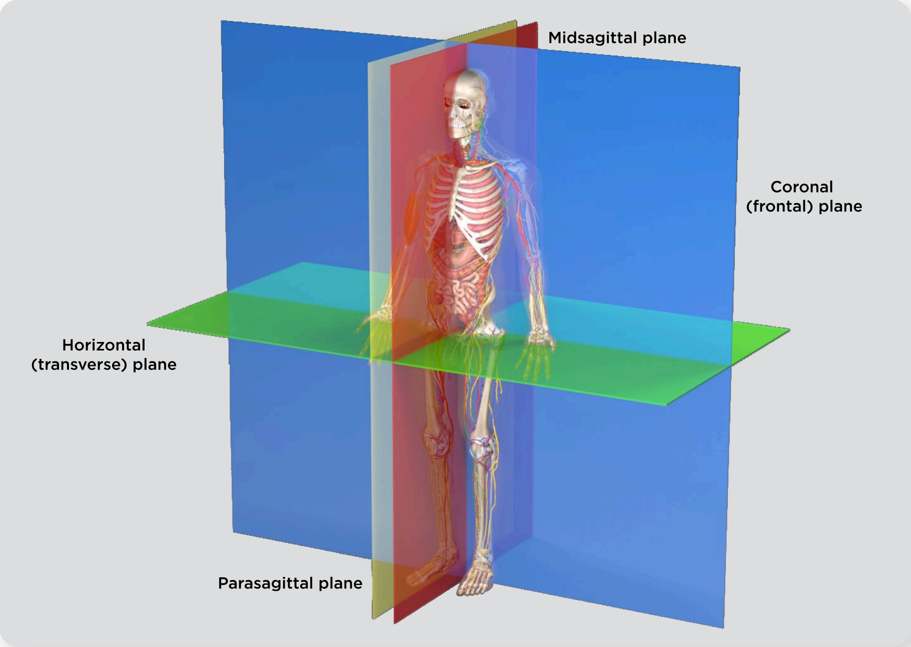
* *Superficial* doesn't necessarily mean "right on the body surface"; it just means "closer to the body surface when compared to something else."

† Occasionally, *proximal* and *distal* are used to refer to other structures. For instance, the proximal end of the small intestine is the region nearest the stomach because that's where the small intestine originates, and the distal portion of the small intestine would be closer to the large intestine, which is where the small intestine terminates.

There are some other terms that you'll need to better make sense of body planes and the types of surfaces created—whether by dissection or by medical imaging techniques like CT scans and MRIs.

From the standard anatomical position, a vertical cut that divides the body into right and left halves creates what's called a sagittal plane. If the cut is directly on the midline, it's called a midsagittal plane, but if laterally, off the midline, it can be called a parasagittal plane. Individual organs or regions, such as the brain or the knee, can also have their own midsagittal plane.

> The creation of specific anatomical terminology has a history that dates back to at least the Roman Empire, when some of the oldest known anatomical treatises were formally laid down.


Midsagittal plane
Coronal (frontal) plane
Horizontal (transverse) plane
Parasagittal plane

A vertical cut that divides the body or a region into anterior and posterior portions is known as a coronal plane, sometimes called a frontal plane, which separates the front from the back.

Dividing the body or one of its structures into superior and inferior regions creates what is known as a horizontal plane, sometimes called a transverse plane or axial plane.

An organ like the brain looks very different when it's viewed in a sagittal plane, coronal plane, and horizontal plane. Body parts or organs can also be sectioned in an oblique plane.

> Scientists advanced our understanding of anatomical structures largely through dissection. And though the body is still dissected today to aid understanding, medical imaging techniques like CT scans and MRIs have revolutionized the ways in which scientists can visualize and study the body.

Reading

Biel, *Trail Guide to the Body*, ch. 1, "Navigating the Body."

Jarmey, *The Concise Book of Muscles*, ch. 1, "Anatomical Terms."

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. A, "General Anatomy."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 1, "Introduction."

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Lecture 2

BONES AS THE BODY'S FRAMEWORK OF MOVEMENT

The skeleton is a fascinating collection of living organs. Did you know that bones are individual organs? And the combination of bones, along with the ligaments and cartilages that hold them together, make up the skeletal system.

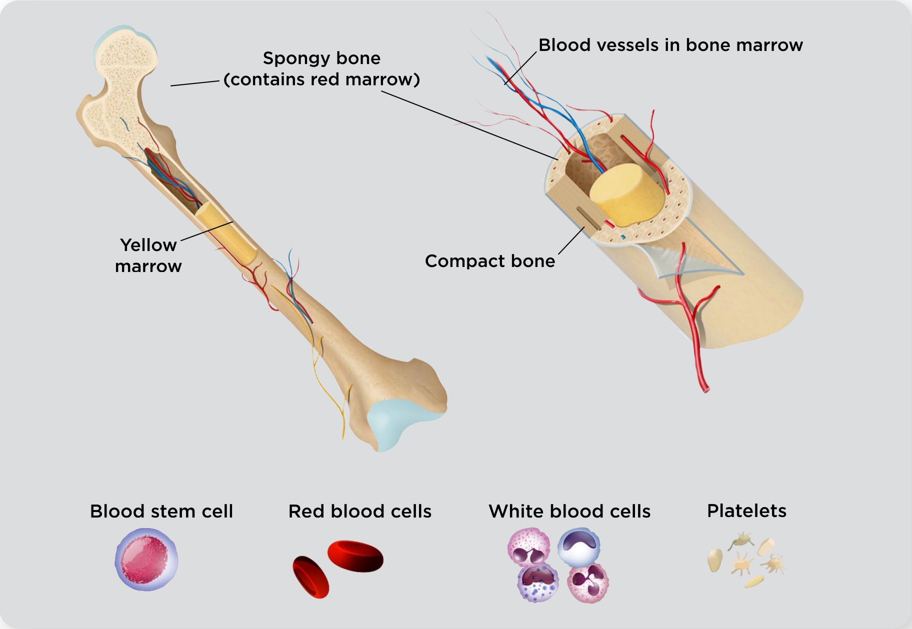
The Skeleton

The skeleton forms the basic structural framework of the body. Not only does the skeleton support the varied soft tissues that make up the rest of the body, but because of the joints between them, bones serve as levers in the leverage systems that cause movement. Muscles supply the force, and the joints serve as the fulcrums in these leverage systems.

Consider the rib cage or the skull and you'll recognize the protective role that the bones provide for more vulnerable and soft internal organs.

One type of bone marrow, known as red marrow—found in flat bones and in the ends of long bones—is a source for the production of new blood cells that move out of the bones and enter circulation.

The major long bones of the body also house yellow marrow, which is the fatty marrow within the hollow shafts of bones like the femur or the humerus. This yellow marrow serves as an energy reserve, since fats have more than twice the caloric value of proteins or carbohydrates.


Spongy bone (contains red marrow)
Blood vessels in bone marrow
Yellow marrow
Compact bone
Blood stem cell
Red blood cells
White blood cells
Platelets

But among the most important roles of the skeleton—and the one that many scientists believe was the original function of bone within the animal body—is to serve as an internal warehouse of minerals. You probably know that calcium is the primary mineral in bone, but bone also houses phosphate salts, with phosphorus being another mineral important to good health. Other essential salts and minerals in bone include carbonates, sodium, magnesium, and potassium. Still other minerals are held in the skeleton in trace amounts. These include iron, copper, zinc, manganese, fluoride, strontium, and boron—all of which are important in various metabolic and enzymatic pathways.

Calcium and phosphate salts crystallize and, together with other minerals, make bones hard and durable. When you have plenty of calcium in the blood, you are able to store some of that incoming calcium in your bones, at least when you're young. Cells of the bone, called osteoblasts, under the influence of hormones, remove some of that calcium from the blood and store it in the bone for later.

When blood calcium levels fall, you have hormones that tell other bone cells, called osteoclasts, to get some of the calcium out of bone storage and put it back into the blood. These cells keep blood calcium levels at their optimal range for all of the other body processes that need it.

This cycling of minerals is called bone remodeling, and it's an important part of bone maintenance. About 10% of bone mineral is turned over each year—so your skeleton is constantly renewed by the process of remodeling. In fact, the minerals currently in your bone represent only about the last 10 years of your life.

If you don't take in enough dietary calcium to offset your body's daily needs, then more calcium is taken from your bones than you replace through your diet. When this happens, bones steadily lose their mineral content. And while you can limit or slow bone loss to some degree with weight-bearing exercise and a good diet, a certain amount of bone loss is inevitable, especially since the ability to build new bone starts a steady decline past around age 40. Sadly, you continue to take calcium out to support physiological needs but lose the ability to replace it in bone, like you could when you were younger.

People typically reach peak bone mass as they approach age 30 and then start to lose bone density by age 40.

The time to build a strong skeleton, then—strong enough to last a lifetime—is when you're young. The best thing to do when you're young to keep blood calcium at levels that won't lead to a loss of bone minerals when you're older is to eat a good diet and supplement with calcium tablets or calcium-fortified foods and drinks. That, plus exercise, will help keep your blood levels high enough to prevent the body's physiologic needs from taking it out of your bones.

> You naturally lose the ability to build bone as you age, but you can help maintain your bone calcium levels through a calcium-rich diet and weight-bearing exercise.

Unfortunately, there are also factors and habits that can negatively impact bone strength, and even accelerate bone loss. These include smoking, excessive alcohol consumption, poor diet, and a sedentary lifestyle. But even without any of these negative factors, at some point, bone mineral loss is inevitable.

Women in particular have accelerated bone loss after they hit menopause, which on a worldwide average happens at about age 50.* Men also have bone loss, and by about age 65 or 70, their rates of skeletal demineralization are about the same as in women, leading to osteoporosis.

When bone is demineralized by osteoporosis, someone's own body weight can be enough to cause a fracture. And when bones are that weak, they have difficulty healing, especially if the blood supply to the bone is disrupted by the fracture.

The Construction of Bone

Bone has widely scattered living cells that are surrounded by and embedded within a connective tissue matrix. For the most part, the cells produce this matrix bed, and then they lie in it. The matrix is mostly composed of a variety of calcium phosphate salts, collectively called hydroxyapatite. These minerals are crystallized around strands of the protein collagen.

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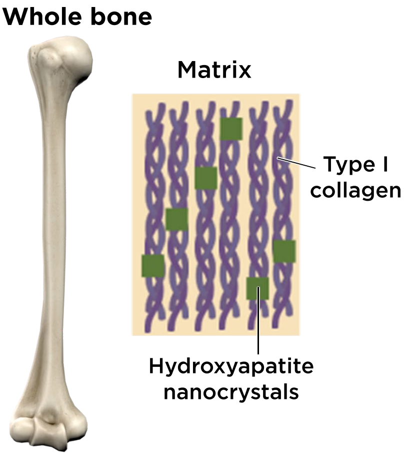
* This occurs at slightly older ages in developed countries and a bit earlier in less developed parts of the world.



Depending on age and health, the overall chemical breakdown of bone is generally about 50% inorganic minerals; around 25% organic compounds, mostly collagen; and about 25% water, much of which is inside the bone cells.

The makeup of bone is similar to fiberglass. Bone's collagen fibers, like the fibers in fiberglass, give bone some flexibility and resiliency. You may not think of bone as being flexible, but it bends before it breaks. It takes a lot of force to break healthy bone. The mineral part of the matrix, on the other hand, gives bone its strength—just like the glass in fiberglass—but it's brittle. It's the combination of the flexible collagen and strong minerals that give bone its remarkable properties.

On average, the adult human body has 206 bones. The number varies with age. There's a general pattern of growth and development in which the skeleton starts as other types of connective tissue, including cartilage. Then, throughout prenatal and postnatal development, some of that cartilage begins to ossify, which means it transitions to bone.

And a typical long bone—such as the humerus of the upper arm or femur of the thigh—doesn't just ossify in a single bony element. First, the shaft, called the diaphysis, starts turning into bone, becoming the bone's primary center of ossification. Then, the two ends, called epiphyses, turn to bone, becoming secondary ossification centers. This process leaves bridges of cartilage between the shaft and its two ends. These are the bone's growth plates: the regions where the bone continues to grow in length during childhood.

Eventually, when the bone has achieved its genetically programmed length—provided good health and nutrition—the growth plates close, fusing the diaphysis to the epiphyses and resulting in a single bone. Long bones of the body grow that way; the skull and other types of bones form from other soft tissues in different patterns of ossification.

When these long bones are developing and still composed of multiple different bony elements, technically we have far more than 206 bones. In the third trimester of fetal life, if all ossification centers are counted, at the highest point the number is about 800 tiny "bones," or separate ossification centers, or bits of bone in formation. Some of these bony elements fuse together in utero, resulting in about 450 "bones" at birth—but sources vary on the exact numbers.

Over anatomical history, sources have varied significantly in the total bone count in the adult skeleton.

But even after the adult skeleton is formed and the last growth region at the medial end of the clavicle closes, the number of bones can still change. For instance, arthritis can fuse vertebrae, the 22 bones in the skull often fuse together in old age, and arthritis or injury can fuse small elements like finger and toe bones. Once that happens, an individual doesn't technically have 206 separate bones anymore.

Still, aside from the changes that occur with age, 206 is an average number of bones in the normal adult. Individuals can be born with extra bones or fewer bones.

In fact, for any given anatomical feature, it's estimated that only 70% of people have the by-the-book pattern for a given structure, meaning that 30% of people have anomalies—and not just from age or an injury that fused bones, but congenitally, from their own genetics and development.

The Classification of Bones

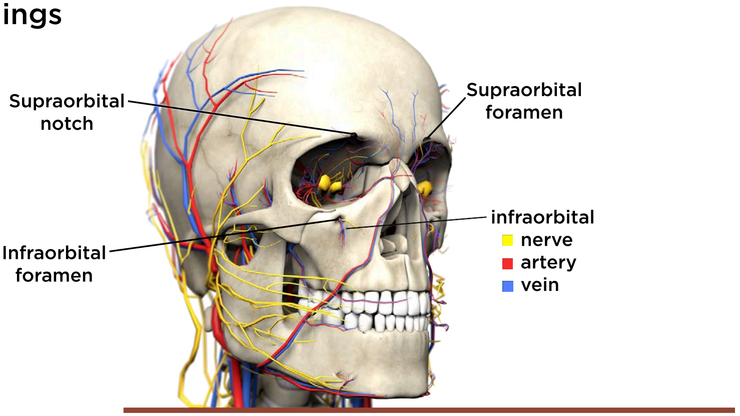
One general concept that's helpful when learning the classification of bones is the contrast between the axial part of the skeleton and the appendicular skeleton. The axial bones are those that make up the main longitudinal axis of the skeleton. These include the 22 bones of the skull; the 6 tiny ossicles in the ears; the single hyoid bone in the neck; the 26 bones of the vertebral column (the 24 individual vertebrae, plus the sacrum and coccyx, or tailbone); the 24 ribs; and the sternum. That's a total of 80 bones.

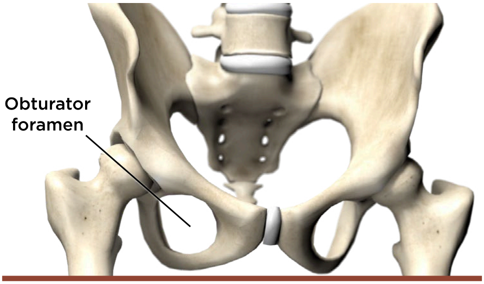
The appendicular skeleton, on the other hand, includes the 30 bones in each upper limb, the 30 bones in each lower limb, the two clavicles and two scapulae of each pectoral girdle, and the pair of pelvic bones that attach the lower limbs to the axial skeleton. The appendicular total is 126 bones, which is 206 when combined with the axial total.

Another general concept has to do with bony landmarks: There are some standard terms used for bone features—such as *foramen*, *tubercle*, and *condyle*—and then adjectives are used to specify those on a given bone.

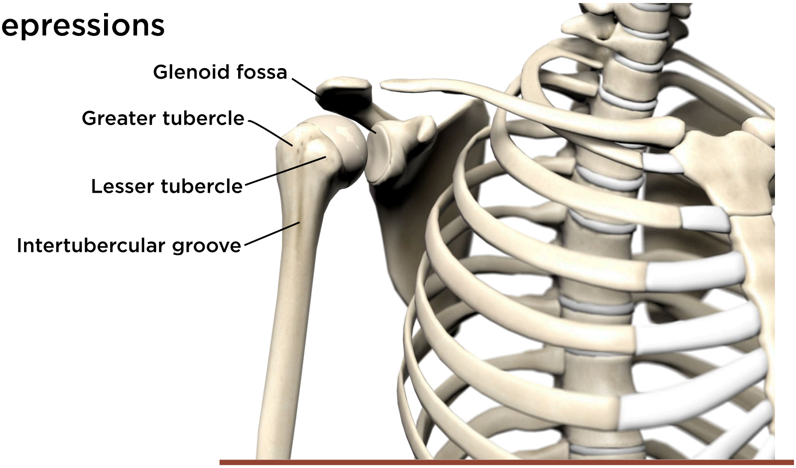
An overarching scheme of bony landmarks boils down to three main categories: projections, depressions, and openings. Depressions and projections are typical of muscle attachment sites and joint surfaces, while openings will transmit arteries, nerves, and veins. Learning the general bony landmark terms in advance will help prevent confusion, since numerous bones have tubercles, notches, heads, facets, and so forth.

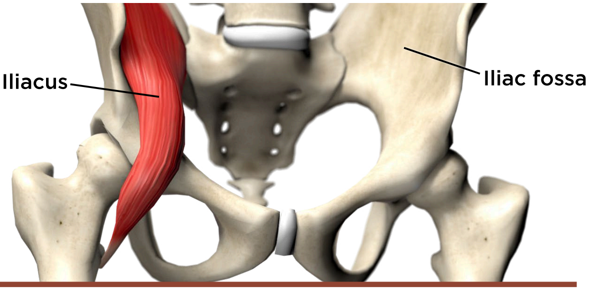
Openings


Supraorbital notch
Supraorbital foramen
Infraorbital foramen
infraorbital
🟨 nerve
🟥 artery
🟦 vein

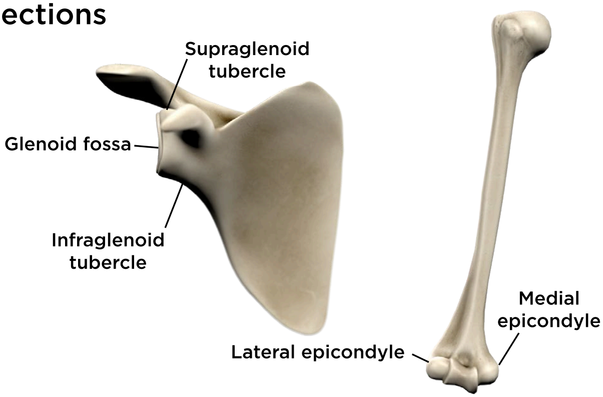

Obturator foramen

Depressions


Glenoid fossa
Greater tubercle
Lesser tubercle
Intertubercular groove


Iliacus
Iliac fossa

Projections


Supraglenoid tubercle
Glenoid fossa
Infraglenoid tubercle
Lateral epicondyle
Medial epicondyle

To some extent, these bony landmarks are there because muscles attach to them. The landmarks don't develop to facilitate the muscle attachment; they grow because bone's reaction to stress is to build more bone matrix.

The matrix is composed of collagen fibers surrounded by calcium phosphate salts. That addition of more bone matrix in response to stress strengthens the bone. According to Wolff's law, bone will adapt to the loads under which it's placed. This is why stress like weight-bearing exercise is healthy for bones (within reason, of course). It is also why inactivity causes bone atrophy.

Human genetics lays down bone in predictable patterns in the skeleton. Genetics also causes muscles to attach in the same places in all of us—within 70% of what's typical. But from the outset, the fetal skeleton has long bones that are very simple in shape—they look like tiny sticks—and lack the typical landmarks of adult bones. As babies begin to use their muscles, the muscles pull on the bone underlying their attachments, and the stimulation helps build the bony landmarks typical of the adult skeleton.

Most people think of the skeleton as static, but it is changing and responsive throughout life.

Reading

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 1, "The Skeleton."

Jarmey, *The Concise Book of Muscles*, ch. 2, "Musculoskeletal System."

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. A, "General Anatomy."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 1, "The Skeleton."

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Lecture 3

JOINTS: STRUCTURE DETERMINES FUNCTION

You might be surprised to learn that not all joints move. In anatomy, a joint is simply an articulation: any place in the body where bone meets bone. There are many, many joints that link the approximately 206 bones in the body. At joints, the articulating bones are linked to each other by ligaments, cartilage, and other tissues that are scientifically classified as connective tissues.

The Classification of Joints

Any joint in the body can be classified in two ways: based on the joint's function—specifically, how much it moves—or its structure, in terms of connective tissue linkages.

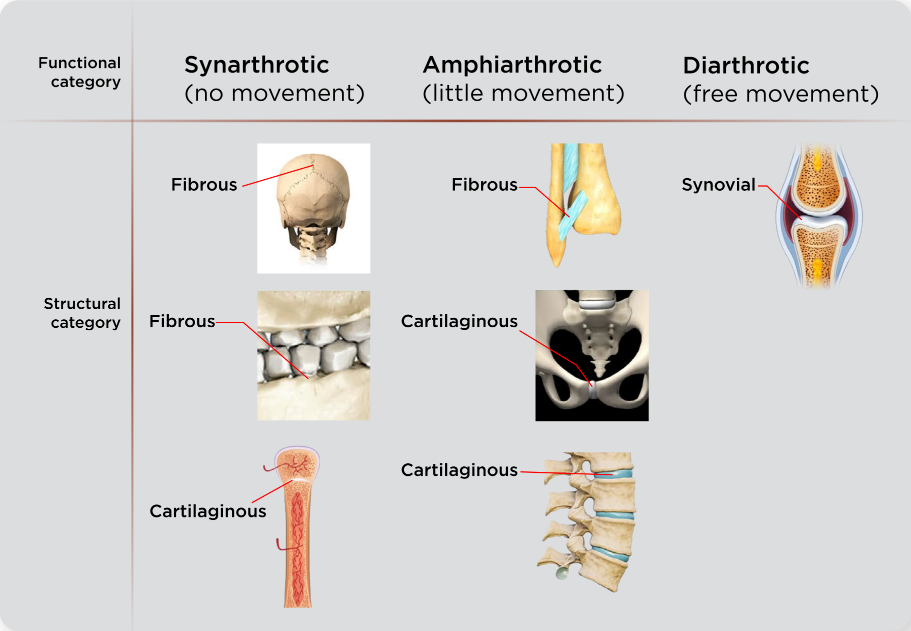
Functionally, joints are classified as synarthrotic, amphiarthrotic, or diarthrotic joints by their degree of movement, since *arth-* is the medical term for "joint." Synarthrotic joints do not move at all, amphiarthrotic joints provide a bit of limited movement, and diarthrotic joints provide free movement in at least two directions.

- In this functional scheme, the prefix *syn-* means "united" or "with." The cranial sutures, which are the joints between bones of the skull, is an example of a synarthrotic joint. Such a place, where bone articulates with bone, is not a joint that allows movement and thus won't be a focus of this course.
- *Amphi-* means "both" or "around." Amphiarthrotic joints are bone-to-bone linkages that allow a fairly limited degree of motion. Examples include joints between two adjacent vertebrae where the intervertebral disks link two bones of the spine. Since those types of joints do allow some movement, some of those will be discussed in this course.
- Articulations with free movement—the diarthrotic joints of the body—will be covered throughout this course. *Di* is a prefix that means "two," because diarthrotic joints are freely movable in at least two directions. This functional classification includes all the stereotypical joints people think of—such as the shoulder, hip, elbow, knee, and joints within the fingers or toes.

In addition to these three functional classifications, there are three structural classifications to which joints can be assigned. Joints that have little or no movement—the amphiarthrotic and synarthrotic joints—are structurally classified either as fibrous joints or cartilaginous joints, based on the type of connective tissue that links the facing surfaces (the adjacent, articulating ends) of the two bones that form the joint.

The diarthrotic joints are the most complex joints in the body and thus are also the most prone to injury and painful dysfunction.

- In fibrous joints, the two bones are united, edge to edge, by some type of dense fibrous connective tissue. These tissue types are loaded with collagen fibers, which is why they are said to be dense. For example, the sutures between bones of the skull are knitted together by what is known as dense irregular fibrous connective tissue. These joints are functionally classified as synarthrotic since they do not move.


Functional category
Synarthrotic (no movement)
Amphiarthrotic (little movement)
Diarthrotic (free movement)
Structural category
Fibrous
Fibrous
Synovial
Fibrous
Cartilaginous
Cartilaginous
Cartilaginous

- The second structural classification is that of cartilaginous joints. In these, the two bones are united together, end to end, by some type of cartilage: a firm, white, flexible tissue. The growth plate in a child's bone is an example of a cartilaginous joint: one in which the shaft, or diaphysis, is united to the bony ends, the epiphyses, by plates of cartilage—specifically a variety of cartilage known as hyaline cartilage. A growth plate is a joint between bones—or really, within a bone—that should not move. In fact, if the growth plate is disrupted by injury, the result can be devastating to the growth of that bone.

- Our freely movable articulations are all structurally classified as synovial joints. In fact, all diarthrotic joints are synovial joints, and all synovial joints are diarthrotic. The term *synovial* refers to the types of fluid-producing membranes that line all of our freely moveable joints. But that membrane is not what makes synovial joints freely movable. These are moveable diarthrotic joints because of the presence of a joint cavity, inside of what's called a joint capsule. The joint cavity is a space between the two articulating bones lined by the synovial membrane, and the capsule is a collective structure that links the bones and surrounds the joint cavity.

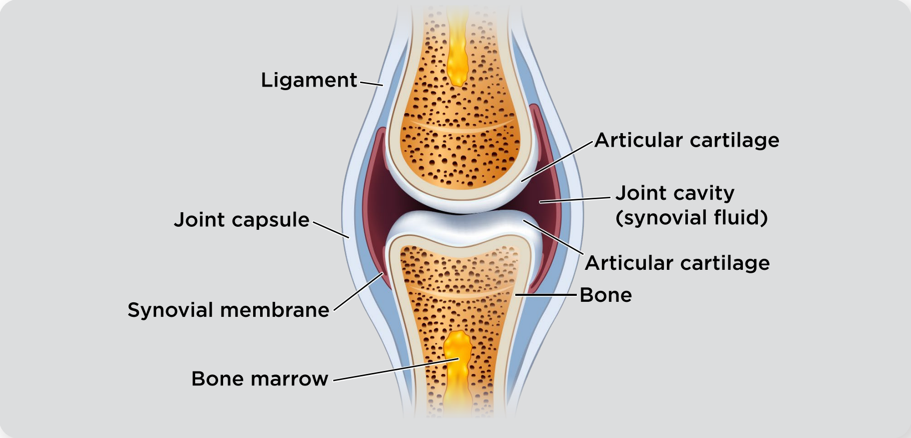
Diving Deeper into Synovial Joints

Synovial joints are the most common articulations in the body—and the most commonly injured.

At the knee, for example, the femur of the thigh meets the tibia of the shin, but the bones are not joined together at their facing articular surfaces, as they are in fibrous or cartilaginous joints. Instead, the bones are held together at other regions—slightly proximal and slightly distal to the actual joint—by the joint's capsule. This capsule unites the bones but leaves their facing surfaces, covered by what's called articular cartilage, free to move against each other. The joint capsule contains the joint cavity, and that space is lined by a synovial membrane.

The synovial membrane is composed of a very thin layer of cells that secrete a mucus-like lubricating fluid. This synovial fluid has two roles: It nourishes the structures within the joint and removes waste products from the joint's tissues. While bones have their own rich blood supply, cartilage is said to be avascular, which means it lacks its own internal blood supply. So the synovial fluid is especially important to the nourishment of cartilage, and the motions that occur at these freely movable joints are good for the cartilage. This is because the movements squish the cartilage while they circulate the synovial fluid around, promoting the release of waste from the cartilage and the uptake of nutrients into it.

In addition to nourishing joint tissues, synovial fluid creates this viscous film of lubricant within the joint cavity, and that aids the free movement possible at diarthrotic joints. These synovial membranes are only found within and around the capsules of synovial joints—thus the naming.



The capsule is an envelope-like structure that in some cases is like a connective tissue sleeve that spans the two articulating bones at a distance from the actual bony joint. The capsule is thickened in regions by ligaments and may have tendons incorporated into it, as well.

In musculoskeletal anatomy, ligaments are usually strap-like or cord-like structures that connect bone to bone, while tendons connect muscle to bone. Both ligaments and tendons contain parallel bundles of collagen fibers for strength and to resist stress in one main direction.

The capsule provides some stability by joining the two bones, while the joint cavity and its synovial membrane lining facilitate movement between the articulating bones. The ligaments reinforce aspects of the diarthrotic joint that need more support, such as on the medial and lateral sides of a hinge joint. These ligaments restrict movement on the sides where they cross the joint space, helping to ensure that movement occurs only in the intended directions.

The capsule is incomplete in places, such as where it allows small blood vessels into the joint or allows a small pocket of synovial membrane to protrude as a bursa. A bursa can be between almost any two structures around a joint, such as between bone and tendon, skin and bone, or bone and ligament. Any bursa that is structurally continuous with the joint's synovial lining can be precarious. *Bursitis* is the medical term for an inflamed bursa. A bursa can be inflamed from infection, injury, or just excess pressure.

Other features that may or may not be present at diarthrotic joints include articular discs, such as the menisci of the knee or the disc within the wrist joint at the distal ulna. When present at a synovial joint, the disc serves as a shock-absorbing pad of fibrocartilage that helps cushion a joint. It can also aid in keeping the articulating bones in position by improving their fit, which helps prevent dislocation. Keep in mind that while these pads may be composed of fibrocartilage, these are still diarthrotic synovial joints, not cartilaginous joints. The articular discs are within the capsule of the joint, surrounded by the synovial membrane.

The capsule also contains sensory nerve endings—and not just for pain, but also for the senses of proprioception or kinesthesia, which relay the locations and movements of our body parts by monitoring joint position and tension on the capsule structures. Our nervous system uses these signals to help us balance as we move, but they are also the reason we know where our body parts are in space without even looking.

Joint Movement

Structure and function are highly interrelated. You may have heard the adage "form follows function"; in anatomy, it is often said that structure determines function.

The directions and degrees of movement at a joint are determined by many factors. One is the specific shapes of the two articulating bones, where they meet each other. A clear example is seen at the elbow. The hinge nature of the elbow joint is obvious just from looking at the structure of the articulating bones. The hook shape of the proximal ulna—which is the more medial of the two bones in the forearm—moves around the spool-shaped end of the distal humerus, allowing bending, or flexion, and straightening, or extension. The large, pointed bony landmark—the olecranon process—at the proximal ulna prevents excessive movement in the opposite direction of flexion, called hyperextension. The normal shapes of the proximal ulna and distal humerus simply don't allow for much backward movement beyond straightening the elbow in extension.

Another factor that can limit range of motion at a joint is the size of the muscles or the amount of body fat in the area. For instance, body builders who have huge biceps may not be able to fully flex at the elbow. Likewise, people who are obese may not get the typical range of motion at some of their joints because excess soft tissues are in the way of the movement.

People who can move in ways that most people cannot—such as contortionists, ballet dancers, or yogis—have trained their ligaments and joint capsules to be increasingly more loose or lax by repeatedly stretching those structures over time in a given direction. There's really no such thing as being double-jointed; people don't have multiple joints where others just have one.

On the other hand, joints that don't get moved and stretched can become increasingly less mobile, such as the syndrome known as frozen shoulder, which is medically called adhesive capsulitis. This can occur when the arm is immobilized for a while, such as following surgery or after a stroke.

Within reason, joint movement is a use-it-or-lose-it proposition. The good news is that most people can recover with treatment—such as using anti-inflammatory medications, getting steroid injections into the joint, and doing physical therapy—but it can take months or even years to resolve. Still other joint pathologies, such as carpal tunnel of the wrist, can result from overuse. Arthritis can also be an overuse syndrome.

Joint movement is a Goldilocks situation: You don't want to use them too much or too little; there has to be a happy medium where things are just right.

Reading

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 3, "Articulations."

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. A, "General Anatomy."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 2, "Overview of Skeletal Anatomy."

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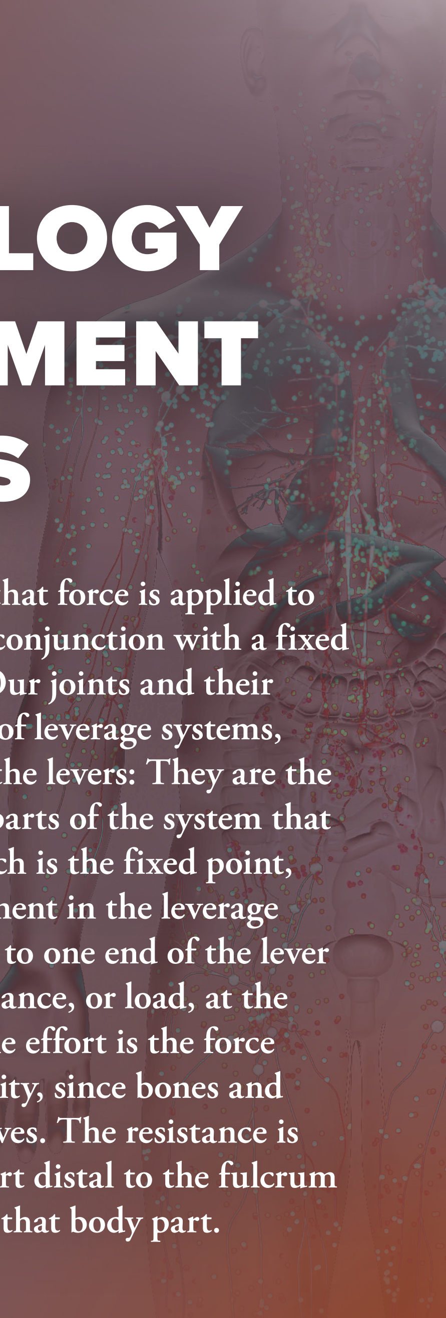
Lecture 4

THE TERMINOLOGY OF MOVEMENT PATTERNS



The way leverage works is that force is applied to an arm, called a lever, in conjunction with a fixed point, called a fulcrum. Our joints and their movements are examples of leverage systems, where the bones serve as the levers: They are the elongated and inflexible parts of the system that move around a joint, which is the fixed point, or fulcrum. To get movement in the leverage system, the effort applied to one end of the lever has to overcome the resistance, or load, at the other end. In the body, the effort is the force generated by muscle activity, since bones and joints can't move themselves. The resistance is the weight of the body part distal to the fulcrum and any added weight on that body part.

Joint Types and Their Motions

The structure of a joint is interrelated with its specific functions. There are six main types of joints, based on the shapes of articulating bones and—as a result of that anatomy—the range of motion they allow. These joint types and their motions vary from simple gliding movements of flat surfaces against each other to angular movements.

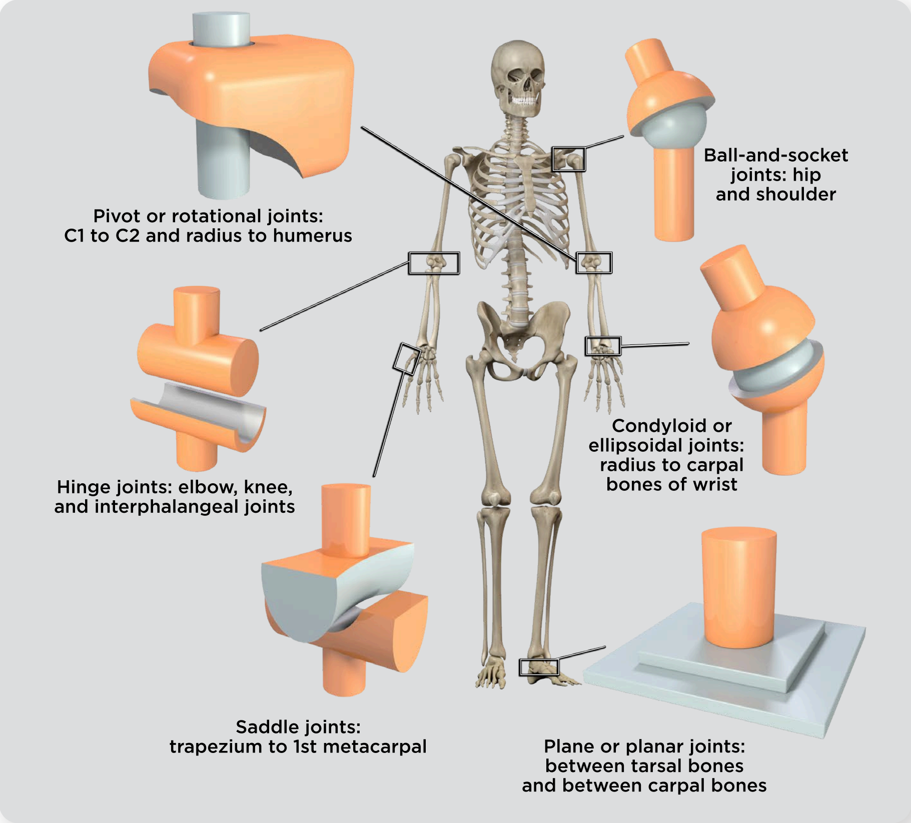
There are six main categories of freely movable synovial joints based on their structure—presented here, to some degree, from simple to complex in their movements.

- **Plane or planar joints** are articulations in which a pair of relatively flat bone surfaces simply slide against each other, such as when using a sanding block against a wooden surface. Since the articulating surfaces never leave each other—they just slide back and forth—these joints don't allow as much movement as many other joint types, but they are still diarthrotic synovial joints. These types of planar joints exist between the tarsal bones in the ankle and foot, for example.

- **Pivot or rotational joints** work like a trailer hitch. Like planar joints, the surfaces don't really leave each other so much as one surface rotates inside a circular or semicircular surface made by the other bone. For this reason, they are known as monoaxial joints, since movement is in a single plane. A pivot joint exists between the first two vertebrae of the neck, allowing us to rotate our head left and right.

- **Hinge joints** are joints where the articulating bones physically resemble a door or cabinet hinge. These are also monoaxial joints that allow movement in a single plane—so only in two directions, such as back and forth, similar to the way a door moves. The knees are hinge joints.

- **Condyloid or ellipsoidal joints** allow a joystick-like movement between a concave oval surface and a matching convex oval surface. The corresponding oval ends of the bones nest in each other like spoons in a drawer. These joints are biaxial because the movement occurs in two planes. A good example of this joint is between the radius of the forearm and a couple of the carpal bones of the wrist.


Pivot or rotational joints:
C1 to C2 and radius to humerus
Ball-and-socket joints: hip and shoulder
Hinge joints: elbow, knee, and interphalangeal joints
Condyloid or ellipsoidal joints: radius to carpal bones of wrist
Saddle joints: trapezium to 1st metacarpal
Plane or planar joints: between tarsal bones and between carpal bones

- **Saddle joints** are relatively rare articulations in which one bone resembles a saddle and the other a rider in that saddle. Saddle joints are biaxial, as they allow movement in more than one direction. The best example of this is where the base of the thumb meets the wrist. This is where the metacarpal bone in the thumb side of the palm joins the lateral-most carpal of the wrist, called the trapezium.
- **Ball-and-socket joints** are multiaxial joints because they allow movement in all three dimensions. These joints allow the greatest range of motion—a complexity of movement that is only possible at the shoulder and hip joints.

Directional Terminology

Now let's cover the terminology for these forward-and-back and side-to-side movements using more specific language—along with some particular joints as examples of places where these movements occur. As with the terms *forward* and *back*, these motions often come in pairs, much like you discovered with directional term opposites, such as *anterior* and *posterior* or *proximal* and *distal*. You will also need to recall standard anatomical position, which has the spine and limbs straight, since these straight lines of anatomical position are also the standard reference positions of joints, from which movements are made.

Flexion and extension are easy to understand in limbs. Flexion is bending, such as at the elbow or knee, and extension returns the body to anatomical position. With regard to the joints within limbs, flexion always decreases the angle between the articulating bones, whereas extension increases the angle between them.

In a sense, our knees and elbows are on backward, in that during flexion at the elbow, the direction of movement is anterior, while it's posterior at the knee. This is due to the rotation that occurs in the lower limb during the development of vertebrates.* However, this angular movement is similar at the ball-and-socket joints of the shoulder and hip, where forward is flexion in both.

Remember *F* and *F*: *Forward* equals *flexion* at ball-and-socket joints. And extension is a posterior movement, restoring the body to standard anatomical position, regardless of upper or lower limb. But once you're within the limb, flexion always decreases the angle of the two bones at the joint.

Flexion of the spine is a forward bend—whether only at the neck or when touching your toes. But you can also do a side bend or move the ear toward the shoulder, which is specifically called lateral flexion of the spine. Extension is returning to a straight spine, as in anatomical position. Sometimes the term *hyperextension* is used for a movement beyond anatomical position.

Another angular movement pair are abduction and adduction—which are possible at ball-and-socket joints but also at condyloid joints like the wrist and the knuckle joints between the fingers and palms. Abduction takes the body part away from the midline, and adduction brings it back toward the midline of the body. Those words are helpful, since if someone is *abducted*, they are taken away, while *adduction* "adds" the body part back to the midline.

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* Vertebrates are animals with a backbone.

Some body parts can have their own midline for abduction and adduction. For example, with regard to the hand, the middle finger is the axis for abduction and adduction with reference to movements of the fingers. Also, remember that abduction and adduction are not possible at the hinge joints of the elbow or knee, since those are monoaxial joints and move only in an anterior and posterior direction, relative to anatomical position.

The arc-like movement called circumduction, which only happens at ball-and-socket joints, simply combines a series of angular motions. You start that circuit with flexion, and then you gradually abduct away from the body; then you move into extension, until you finally adduct back toward the body, returning to anatomical position. That's different from rotational movements, such as happen at pivot joints.

In terms of true rotational movements, there is a pivot joint between the first and second vertebrae of the spine that looks and functions like a trailer hitch. The second cervical vertebra has a projection that sticks up, and the first cervical vertebra, with the skull on top of it, rotates around that projection, giving a much greater range of side-to-side motion of the head than at other places in the spine. Rotational movement also happens at the elbow, specifically at the part of the elbow joint between the radius and the humerus.

Perhaps because our upper limbs are so important to our daily lives, there's a special name given to the rotational movement between the humerus and the radius. *Supination* is the term for palm forward, like in anatomical position, and *pronation* is the opposite term for when the palm is turned backward, or posteriorly. You can use this memory trick: "You can hold a bowl of soup in a supinated hand, but if you turn that hand over, you are prone to drop the soup."

Supine and *prone* are also used for positions on a surgical table or gurney. Supine is belly-up, and prone is facedown. And while those aren't movements, they are deviations from anatomical position and come from the same word roots as *supination* and *pronation* of the elbow.

Other rotational movements happen at ball-and-socket joints. Inward, internal, or medial rotation is performed in the lower limbs when pointing the toes toward the midline; lateral, outward, or external rotation is the act of pointing the toes out toward the sides. As an example, the knee can't do that kind of rotation; that action is happening at the ball-and-socket joint of the hip.

Just as pronation and supination are particular to the elbow, some other movements are specific to only a select joint. There's a special set of movements of the foot known as inversion and eversion. Inversion refers to directing the sole of the foot toward the midline, while everting the foot directs the sole of the foot outward, away from the body. These movements are often said to happen at the ankle, but they actually happen within the foot itself, not between the leg and foot at the ankle joint.

The special actions that do happen at the true ankle joint are a pair of movements called dorsiflexion and plantar flexion. Dorsiflexion means pointing the toes toward the ceiling, like walking on your heels, and this happens at the hinge joint of the ankle. Plantar flexion is the opposite movement that points your toes down toward the floor, like standing on your tiptoes. The true ankle joint is a hinge joint, while a series of gliding joints within the foot allow the movements of inversion and eversion.

Protraction and retraction are a set of movement classifications that occur at a limited number of joints. *Protraction* means "to protrude a body part, pushing it anteriorly," while *retraction* is the opposite, pulling that body part back to anatomical position, or pulling it in a posterior direction. An example of this is seen at the shoulders with the scapula, or shoulder blade, and with clavicles, commonly called collarbones. You protract your scapulae when you push your shoulders forward, and you retract them when you pull them together posteriorly—like you do when correcting poor posture.

> You dorsiflex your ankle to move from the gas pedal to the brake, and then you plantar flex your foot to press down on the brake pedal.

The scapulae of the shoulder girdle can also elevate and depress: When you shrug your shoulders, you are elevating your scapulae and the clavicles that connect to them, and then you can also depress the shoulder girdle, bringing the shoulders down away from your ears.

Lastly, consider the hand. The saddle joint between the thumb and one of the carpals of the wrist allows the pretty remarkable ability of primates like monkeys, apes, and humans to oppose the thumb to their other fingers. This makes for a prehensile, or grasping, hand: an exceptional feature that is one of the hallmarks of our species. *Opposition* is the term for that movement of the thumb, and *reposition* is the opposite of opposition.

Of all the elements of the musculoskeletal system, joints are the only components that are readily and frequently replaced by artificial substitutes, known as prosthetic joints. The history of joint replacement surgery goes back to the 1800s in the United States, but so-called total joint replacements didn't begin until about the 1970s.

Reading

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 2, "The Body in Motion."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 2, "Movements of the Body."

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Lecture 5

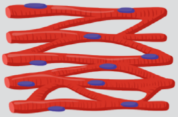
MUSCLES AS SYSTEMS FOR MOTION AND SUPPORT

Various types of cells link together to make up the many types of tissues of the body, and different tissues combine to form organs. When it comes to muscle tissue, there are three types: cardiac muscle, smooth muscle, and skeletal muscle.

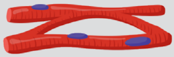
Types of Muscle Tissue

The three types of muscle tissue are differentiated by their microscopic structure and by whether we can voluntarily control them—and this corresponds to their relationship with the nervous system. In fact, we have distinct divisions of the nervous system related to the control of voluntary muscle versus the subconscious control of involuntary muscle.

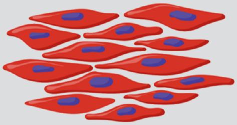
- Cardiac muscle is only found in the heart. It makes up the walls of the heart chambers and is one of the two types of involuntary muscle. That means that we cannot control its action directly. Sure, we can increase our physical activity level, and that will cause the heart to beat faster and with more force, but that's indirect control. When an unfortunate person is suffering from atrial fibrillation or a heart attack, they cannot will their heart back into rhythm or make it start beating again.
- The name *smooth muscle* is due to the internal appearance of the cells in this type of muscle, but it is also involuntary muscle that we cannot consciously control. Smooth muscle is typically found in the walls of hollow organs, such as the stomach, the bladder, the uterus, and the walls of blood vessels. It's also found in other locations, such as the tiny muscles in the skin that give us goosebumps or in the iris of the eye to cause the pupil to dilate or constrict.
- Skeletal muscle is so named because of its general ability to move the bones of the skeleton through its attachments. This is voluntary muscle tissue, which is subject to our conscious control. However, we can develop what become basically subconscious patterns of muscle action—sometimes called muscle memory—such as knowing how to drive a car without really thinking about it.



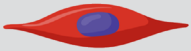
Cardiac muscle



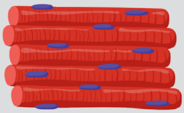
Involuntary muscle



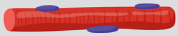
Smooth muscle



Involuntary muscle



Skeletal muscle



Voluntary muscle

Roles of Skeletal Muscle

As a tissue, skeletal muscle has several major functions. Body part movement is an obvious function, but not all skeletal muscle movements are as plain to see, such as more subtle movements like breathing. Skeletal muscle movements are also used in our communication, whether through speech and handwriting or through nonverbal communication with facial expressions and body language. Though cardiac and smooth muscle also cause movements, those are more internal and are typically not obvious from the body surface, with a few exceptions, such as goosebumps.

By contrast, some of our stillness also comes from muscle contraction, such as the postural muscles that keep our spine erect or our legs straight when we are standing. Skeletal muscles that surround joints can also hold fast to help stabilize those joints. This is because skeletal muscle can contract and generate force without actually causing movement.

In addition, skeletal muscle sphincters govern the outlets of the urinary and digestive systems. In each case, there's a smooth muscle sphincter that is more internal and a voluntary skeletal muscle sphincter that is more external. When the bladder or bowel is full, the involuntary sphincter will relax, but when we were potty trained, we developed learned voluntary control of the external sphincters, which help us stall elimination until we get to the right time and place.

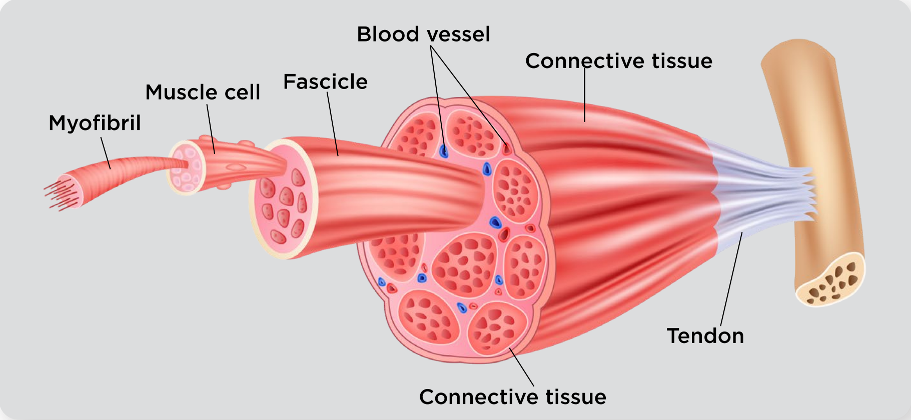
A lesser-known role of skeletal muscle tissue is in heat production. As much as about 85% of our normal body heat is due to the action of skeletal muscles. The reactions that occur within the muscles generate heat as a by-product. This is why we get hot when we exercise vigorously and why we sweat to dissipate some of that body heat.

Lastly in terms of physiology, skeletal muscle activity helps regulate glycemic control. In other words, exercise is good for the proper maintenance of blood sugar. Muscle action doesn't just use up glucose, which is the transport form of sugar in the blood; cells need insulin to take up and utilize the glucose from the blood. Scientific research shows that regular exercise can improve the body's use of and sensitivity to insulin.

How Muscles Work

References usually quote between 600 and 800 muscles in the body.

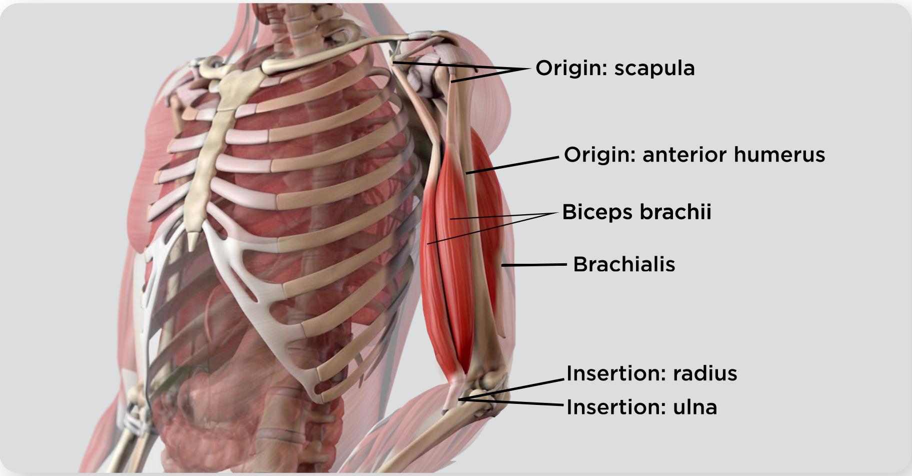
Each muscle is considered an individual organ, since organs are composed of multiple tissue types. Skeletal muscle tissue qualifies because it also has some connective tissues within it to help it work and give it more stability. Those connective tissues become one with the tendons at either end of a muscle. In other words, the tendons that connect muscle to bone don't disappear; they spread out throughout the muscle and compartmentalize it into bundles of related muscle cells that act as a unit.



The packing of muscle cells into groups called fascicles gives skeletal muscle a grain: a striated appearance of directionality that is very helpful in understanding a muscle's action. Muscles do come in different shapes and sizes, and those shapes not only have names but also relate to the action of that muscle. Muscles and the cells within them shorten to execute movement, so the ability to see the directionality, or grain, within a muscle is key to understanding how it acts on the bones it's connected to.

Generally, each muscle has a tendon of attachment at either end, and the fleshy mass between the two is called the muscle's belly. A typical fusiform muscle—one that tapers at both ends—is the biceps brachii of the arm.

The tendon of attachment to the bone that the muscle does not move is called the muscle's origin. The tendon of attachment to the bone that the muscle moves is known as its insertion.* In the case of the biceps brachii, there are two origins; as the *bi-* of its name implies, it's a two-headed, or two-bellied, muscle. It has what's known as a long head and a short head, and the origins of both of those are on the scapula.



But saying that those are the origins of the biceps brachii doesn't mean the scapula cannot move; it just means that moving the scapula is not the job of the biceps brachii. In fact, there are many muscles that act on the scapula. The tendon of insertion for the biceps brachii attaches to the radius in the forearm, and although the biceps brachii crosses both the shoulder joint and the elbow joint, its main role is to flex the elbow.

Knowing where a muscle is relative to a joint is key to knowing its action.

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* Not all references use the terms *origin* and *insertion*; some sources use *superior* and *inferior* attachment, or for other muscles use *proximal* and *distal* attachment. This is because the role of a given muscle can change depending on body position.

Since the biceps brachii crosses the front of the elbow, and given that muscles shorten to cause movement, you can think of muscles like puppet strings: If the biceps brachii passes anterior to the elbow joint and inserts on the radius just distal to the elbow joint, it will flex the elbow.

But the biceps brachii is not the only muscle that flexes the elbow. There is another muscle, lying deeper than the biceps brachii, called the brachialis, which originates on the humerus by a broad, flat attachment—along the anterior surface of the humerus, more so than a defined tendon. And it inserts on the ulna of the forearm.

Keep in mind that joint movements have partners. If the biceps brachii and brachialis work together to flex, or bend, the elbow, which muscle extends the elbow?

The triceps brachii is in the posterior arm and, as indicated by the prefix *tri-*, has three bellies, or heads. One of the three heads originates on the scapula, while the other two originate on the humerus—by broad, flat attachments, like the brachialis has, rather than a visible tendon.

So the job of the triceps brachii is not to move either the scapula or the humerus. Triceps brachii inserts on the olecranon process of the ulna—that pointy prominence on the back of your elbow. Because the triceps inserts on the ulna, its job is to move the ulna, and because it is positioned posterior to the elbow joint, by that puppet string logic, the triceps brachii functions to extend the elbow.

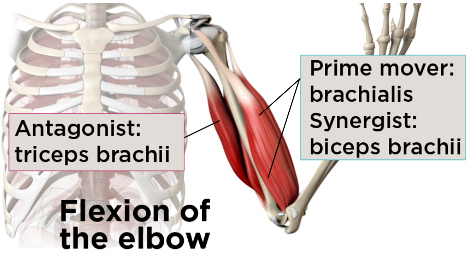
More important than studying these specific muscles is using them to understand some basic principles of muscle shape, position, and attachments. More generally, let's consider how muscles work in groups.

The main muscle that causes a given action is called the prime mover or agonist for that action. And a muscle that assists in a given action is termed the synergist for that movement. A muscle that must relax in order for a prime mover and its synergists to act is called an antagonist to the given movement.

So, the prime mover for flexion of the elbow is the brachialis, and the biceps brachii is its synergist, or assistant. The triceps brachii must relax in order for elbow flexion to occur, so it is the antagonist in elbow flexion.

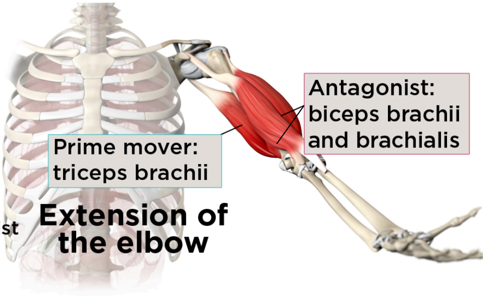
Agonist (prime mover)
- primary muscle for a given movement

Synergist
- aids agonist, stabilizes an action


Antagonist:
triceps brachii
Prime mover:
brachialis
Synergist:
biceps brachii
Flexion of the elbow

Antagonist
- muscle that must relax for agonist and synergist to act

Fixator
- specialized synergist
- stabilizes the origin of an agonist to better facilitate the action of the agonist


Antagonist:
biceps brachii
and brachialis
Prime mover:
triceps brachii
Extension of the elbow

In the extension of the elbow, the roles reverse, and the triceps brachii becomes the prime mover, and the biceps brachii and brachialis must relax, so those two muscles become the antagonists to triceps brachii.

A muscle acting as a fixator, or stabilizer, in a given action is a muscle that holds a bone in position so that another muscle can act. Good examples of this are at the scapula, which is a freewheeling, mobile bone. There are several muscles around the scapula that insert on it to help hold it in place so that the other muscles that originate on the scapula can do their job of moving the humerus, for instance.

> Muscles do not have to shorten to generate force. They must contract and generate tension, but they don't necessarily have to shorten—nor does that force have to cause movement.

How Muscles Are Named

Let's use biceps brachii and triceps brachii as a general introduction to how muscles are named.

The brachium is the arm region, between shoulder and elbow, so that informs us of the muscle's location, and the pairing of the adjectives *triceps* and *biceps* also tells us that one has two heads, or bellies, and the other has three.

But not all muscles are named that way. Muscles are also named for the direction of their cells and, as a result, the direction of their fascicles, or grain. For example, the external oblique is an abdominal wall muscle with obliquely oriented fibers, and the orbicularis oris is a circular, or orb-shaped, muscle around the mouth, as in *oral*.

Muscles are also named for their relative size, such as gluteus maximus and gluteus minimus. Again, those are some helpful adjective pairings that give the size of two closely associated muscles. Sometimes, though, a single adjective is used for two different body regions—as with biceps brachii of the arm and biceps femoris of the thigh.

Some muscles are named for their shape, such as the deltoid of the shoulder, which is relatively triangular shaped, like the Greek letter delta. Other muscles are named for their action, such as the levator scapulae, which elevates the scapula.

Strategies for Learning the Body's Muscles

When it comes to learning the many muscles of the body, examining images is very helpful—especially isolated images of a muscle that include its origin and insertion. Also, you can palpate the muscle on yourself while moving it to feel it develop tension, perhaps while saying its name. Learning the meaning of the terminology used in muscle naming can also be very helpful.

Still other muscles are named for their origin and insertion, such as sternocleidomastoid, named for its attachments to the sternum, clavicle, and mastoid process behind the ear.

Reading

Dimon, *Anatomy in Action*, ch. 1, "The Musculoskeletal System and Its Dynamic Design"; ch. 2, "How the System Works."

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. A, "General Anatomy."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 3, "Overview of Muscle Groups and Their Functions."

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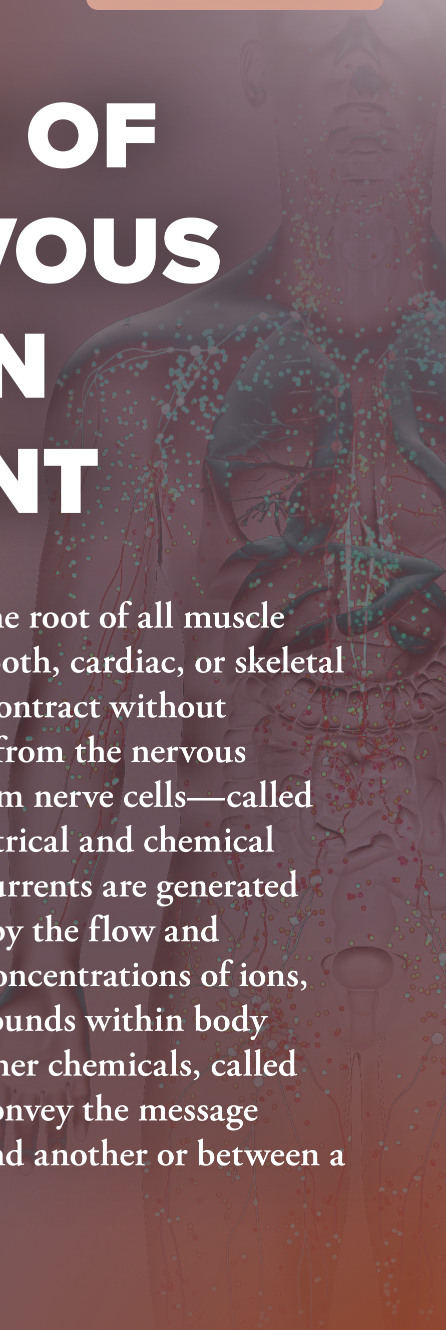
Lecture 6

THE ROLE OF THE NERVOUS SYSTEM IN MOVEMENT



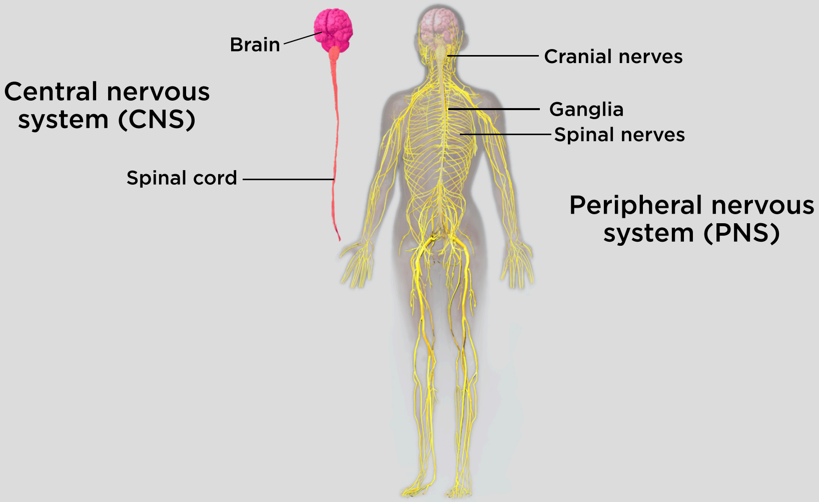
The nervous system is at the root of all muscle movements, whether smooth, cardiac, or skeletal muscle. Muscles do not contract without first receiving a message from the nervous system. These signals from nerve cells—called neurons—have both electrical and chemical components. Electrical currents are generated within the human body by the flow and differences in chemical concentrations of ions, which are charged compounds within body fluids and body cells. Other chemicals, called neurotransmitters, can convey the message between one nerve cell and another or between a neuron and a muscle.

The Anatomy and Physiology of the Nervous System

The anatomy of the nervous system is primarily divided into two main components: the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS consists of only two organs: the brain and the spinal cord. The PNS, on the other hand, is made up of all other nerve tissue; this could be summarized as the body's nerves and structures called ganglia.

The brain is a mass of neural tissue housed inside the cranial cavity of the skull. The spinal cord is connected to the brain and housed within the vertebral column: the bones and structures that make up the spine. So, the skull and vertebrae protect and safeguard the two organs of the CNS, but each of those CNS organs has nerves extending off of it that exit the cranium or leave the spine to form the PNS.

The nerves attached to the brain are called cranial nerves, and nerves extending from the spinal cord are known as spinal nerves. The other component of the PNS, the ganglia, are limited areas where the nuclei of some nerve cells are found outside the CNS.



In addition to being subdivided anatomically, the nervous system can be subdivided physiologically into the somatic nervous system (SNS) and the autonomic nervous system (ANS). The SNS controls voluntary skeletal muscles and conveys most of our conscious sensations to the brain. The ANS controls involuntary cardiac and smooth muscle as well as many glands of the body. The SNS is the focus here.

In terms of functionality, much of the SNS can be divided into sensory pathways and motor pathways. Sensory pathways bring information into the CNS from the periphery, such as from sensory receptors in the skin, joints and muscles, and other internal organs. Sensory pathways are the input to the CNS and are also known as afferent pathways. Motor pathways, on the other hand, carry commands from the CNS—either from the brain or spinal cord—to nerves of the PNS.

With regard to neuromuscular relationships, these motor nerves will either stimulate the skeletal muscle to contract or inhibit the muscle, telling it to relax. These outgoing motor signals are also known as efferent pathways. The motor neurons themselves can be called efferent neurons, and sensory neurons are also known as afferent neurons. A memory trick is to consider the word *same*: The *sa-* in *same* helps you remember that *sensory* means *afferent*, and the *-me* in the word helps remind you that *motor* is *efferent*.

The Cranial and Spinal Nerves

Most cranial nerves usually relate to sensory input from the head—including our special senses,* which are sight, smell, taste, hearing, and equilibrium—and motor control to the head and neck. Most spinal nerves carry sensations from the trunk and limbs and motor control to the trunk and limbs.

There are 12 pairs of cranial nerves that come directly off the brain and exit the cranial cavity by various holes in the skull, generally called foramina. But some of these passageways are more tubelike and are called canals, while others are more slit-like and are called fissures. Regardless, a few of the cranial nerve pairs are entirely sensory in their function, such as those that relay the special senses of sight and hearing.

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* While general senses are found all over the body and have relatively simple receptors, special senses have complicated receptors, all of which are located in the head.

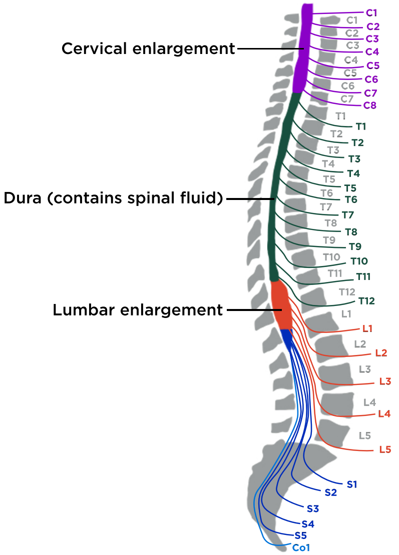
Some other cranial nerves are entirely motor, meaning that their sole function is to control muscle—whether skeletal muscle, smooth muscle, cardiac muscle, or a combination of those. And still other cranial nerves are both sensory and motor and cover a myriad of functions, most of which are in the head and neck. But nine of the 12 pairs of cranial nerves govern some of our voluntary skeletal muscles, and all of those muscles are wholly or partly in the head or neck.

There are 31 pairs of spinal nerves that come directly off the spinal cord. They exit the vertebral column by openings formed between the vertebrae, where they are stacked on each other. Because these holes form between adjacent vertebrae, they are known as intervertebral foramina.

The brain initiates our voluntary movements and even generates defined and coordinated pathways for our collective actions that are called muscle memory. The memory isn't in our muscles but is a coordinated series of neural pathways that we store in our brain. These allow us to remember and perform an activity like how to steer a car once we've learned it. Reflex activity uses many of the same neurons and the same nerves but operates on shorter pathways.

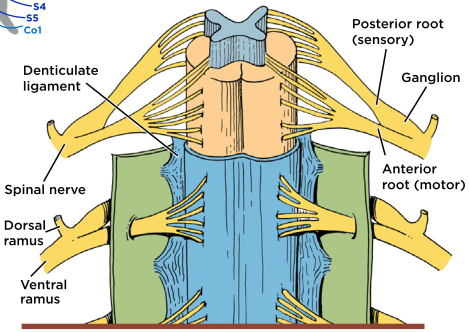
There are 24 vertebrae, plus a sacrum and coccyx (tailbone), and spinal nerves also exit from those. The net result is 31 pairs of spinal nerves, which share their naming with their respective vertebrae. There are eight pairs of cervical nerves in the neck region, 12 pairs of thoracic nerves in the area of the rib cage, five pairs of lumbar spinal nerves in the low back, five pairs of sacral nerves that exit holes in the sacrum, and one pair of coccygeal nerves that exit between the sacrum and coccyx.

All 31 of these pairs of spinal nerves are considered mixed, relaying both sensory and motor information.


Cervical enlargement
Dura (contains spinal fluid)
Lumbar enlargement
C1
C2
C3
C4
C5
C6
C7
C8
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
S1
S2
S3
S4
S5
Co1

Spinal Cord

- 31 pairs of spinal nerves
  - 8 cervical
  - 12 thoracic
  - 5 lumbar
  - 5 sacral
  - 1 coccygeal


Posterior root (sensory)
Ganglion
Denticulate ligament
Spinal nerve
Anterior root (motor)
Dorsal ramus
Ventral ramus

Starting at the spinal cord, each spinal nerve offshoot comes from the convergence of an anterior, or ventral, root with a posterior, or dorsal, root. Each anterior root is entirely motor, meaning that all of the neural pathways in it are outgoing efferent pathways from the CNS, such as to smooth muscle or skeletal muscle. Each posterior root is entirely sensory, in that all of the neurons in this structure are carrying incoming sensory afferent information from receptors in the periphery, such as touch receptors in the skin.

When these two roots come together, they form a spinal nerve, which is considered a mixed nerve, both sensory and motor in nature. This convergence of the anterior and posterior roots happens just before the resulting spinal nerve exits the intervertebral foramen. Then, almost immediately, each of the spinal nerves divides into a pair of distributional branches, known as rami (the singular form is *ramus*). The larger of the pair is called the ventral ramus, and the smaller of the pair is known as the dorsal ramus of that given spinal nerve.

The Dorsal and Ventral Rami

The dorsal rami of spinal nerves supply the true back muscles, whose job is to support and move the spine. Calling them true back muscles differentiates them from other muscles, such as some of the rotator cuff muscles, that are located on the back to gain their leverage but are really acting on an upper limb.

So, the motor axons, or motor fibers, that start in the spinal cord travel out the anterior root, become part of a mixed spinal nerve, and then—if they are headed to the true back muscles that operate the spine—they will travel through the dorsal ramus of the spinal nerve. True back muscles are the motor job of a dorsal ramus. The sensory job of a spinal nerve's dorsal ramus is to relay sensations from the skin of the middle third of the back.

If someone taps you right in the middle of your back, that sensation is traveling into your CNS by passing through a dorsal ramus, then into a spinal nerve, and then—since touch is a sensory function—passing into the spinal cord by a posterior root before passing up ascending tracts until you finally perceive that tap on the back in your brain. And amazingly, all of this takes only fractions of a second!

Each spinal nerve is responsible for sensation from a given patch of skin known as a dermatome. The territory from the back of the head, down to a taper that ends at the so-called natal cleft—which is the technical term for the butt crack—is the sensory turf that belongs to the dorsal rami of the spinal nerves. Moving from that middle third out to the more lateral aspects of the back, you begin to run into the ventral ramus territory of that same spinal nerve.

The ventral rami are more complicated than the dorsal rami. The ventral rami relay the sensations from the skin down the middle of the back and carry the motor control over the true back muscles. They assign all other functions attributed to spinal nerves to the ventral rami. But remember, cranial nerves govern most of the sensory and motor functions in the head and neck. So, if dorsal rami are concerned with the skin down the middle third of the back and the back muscles that actually operate the spine, then ventral rami are concerned with everything else that isn't supplied by cranial nerves.

In terms of their sensory function, ventral rami transmit the sensations for all other skin below the head. This means the skin of the two lateral thirds of the back, the entire skin of the anterior and lateral trunk, and all of the skin of the upper and lower limbs—but not the skin of the face. Sensations from there travel by a cranial nerve. That's the extensive sensory or afferent function of a ventral ramus of a spinal nerve, so what about its motor function?

Again, this is part of the "everything else" that's not supplied by a cranial nerve and not supplied by a dorsal ramus. So, ventral rami of spinal nerves control the motor functions of all muscles of the trunk and all muscles of the limbs, whether anterior or posterior, other than the true back muscles. This includes the muscles of the chest, abdominal wall, pelvis, pelvic floor, all the muscles that are within the limbs, and all the muscles that control upper or lower limb movement. Some of these, such as the latissimus dorsi, happen to live on the back in order to gain leverage, cross the shoulder joint, and move the upper limb.

The right side of the brain controls the left side of the body, and vice versa. That's the reason a person who has a major stroke on the left side of their brain will lose control of right-side body muscles and will also not be able to sense things on the right side.

Ventral rami have essentially two main fates. First, in the thorax, the ventral rami assume a relatively simple pattern by hugging a rib as it proceeds around the chest wall. These ventral rami are called intercostal nerves, and they supply the muscles that move the rib cage and those of the anterolateral abdominal wall. These intercostal nerves also receive sensations from the dermatomes of the lateral and anterior trunk. So, the ventral rami of thoracic nerves can synonymously be called intercostal nerves because they travel between ribs.

The second fate that a ventral ramus can assume is to become part of a nerve plexus. The term *plexus* is Latin for "braid" or "plait," and the ventral rami of spinal nerves, other than those in the thorax, braid together into what's called a plexus. For example, the cervical plexus and the lumbar plexus are braids of ventral rami that overlap to supply a given body region. These nerve plexuses are entirely composed of ventral rami originating from either superior to or inferior to the intercostal nerves that assume the simple rib-hugging pattern. No dorsal ramus has any role in any of those plexuses, because they supply the skin of the back and true back muscles.

Reading

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 12, "Muscle Innervation Pathways."

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. A, "General Anatomy."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 4, "Innervation of the Muscle Compartments"; ch. 8, "The Central Nervous System in Relation to the Musculoskeletal System."

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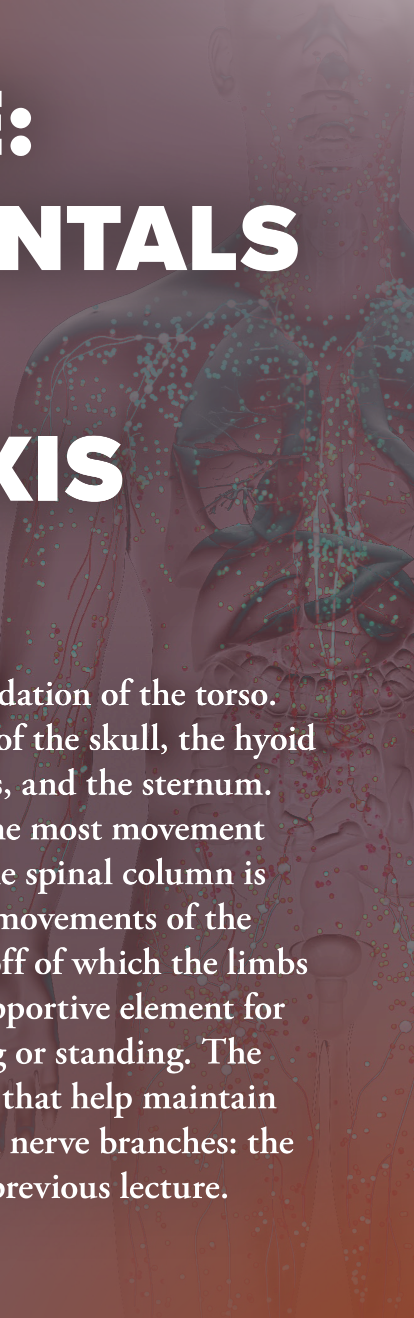
Lecture 7

THE SPINE: FUNDAMENTALS OF THE BODY'S AXIS



The spine is the skeletal foundation of the torso. The axial skeleton consists of the skull, the hyoid bone, the vertebrae, the ribs, and the sternum. But of all those elements, the most movement occurs within the spine. The spinal column is the axis of our major body movements of the trunk. It is a flexible strut off of which the limbs extend, and it is a major supportive element for our posture, whether sitting or standing. The so-called true back muscles that help maintain that posture have their own nerve branches: the dorsal rami covered in the previous lecture.

The Vertebrae

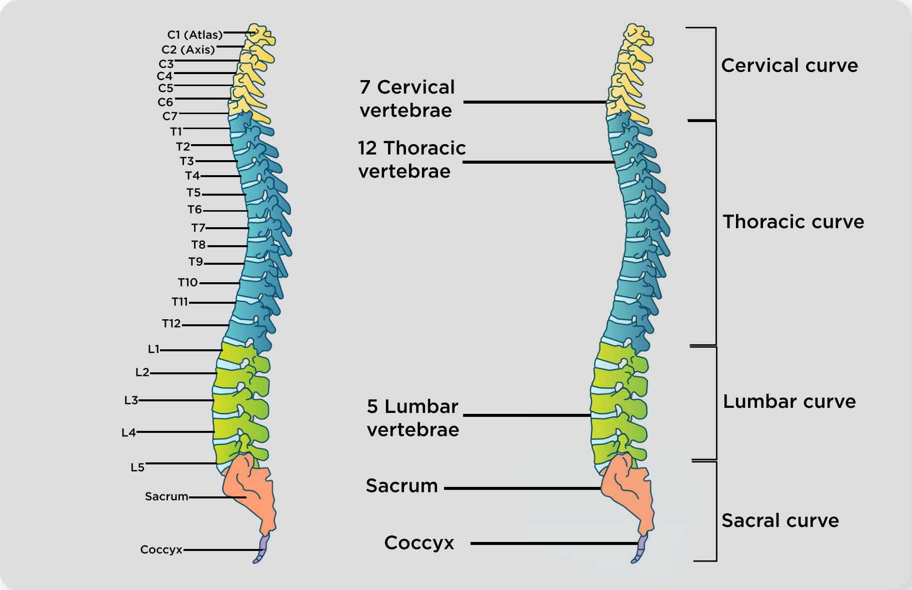
The segmental nature of the spine can be seen in the repeating series of 24 vertebrae, along with the sacrum and coccyx. The stacking of these elements provides both the support and flexibility needed for posture and movement. The vertebral column is broken down into five main regions: a series of seven vertebrae in the neck called cervical vertebrae, 12 vertebrae in the rib cage known as our thoracic vertebrae, five spinal elements in the low back called lumbar vertebrae, the sacrum, and the coccyx.

The sacrum is usually formed from five sacral vertebrae that unite during development into a single triangular bone, typically when you're in your teens. The coccyx fuses from three or four small elements in humans. In four-legged animals that have a tail, a series of caudal vertebrae extends from the sacrum into the tail. Humans only have a tail when we're embryos, and those few coccygeal vertebrae are the vestigial remnant.

Nearly all vertebrae have a central region known as the vertebral body. Connected to that is a neural arch composed of two main parts: a pair of pedicles, which are stalklike extensions that attach the neural arch to the vertebral body, and a pair of laminae, which complete the neural arch by meeting each other posteriorly. This arch surrounds an open region called the vertebral foramen, in which the spinal cord and its nerve roots reside. Above each pedicle is a superior articular process, and below each pedicle is an inferior articular process.

Remember that an articulation is a joint, so these facets are part of the anatomy that links the bones of the spine together. Laterally off the neural arch are a pair of transverse processes, so called because they go in a transverse orientation, and posteriorly there's a spinous process that extends off of the posterior aspect of the laminae. These processes—like many projections off of bones—serve as attachment sites for ligaments and muscles.

A shorthand is used when discussing the vertebrae. For each, the numbering starts at the top of each section and proceeds inferiorly. So the seven cervical vertebrae are typically referred to as C1, C2, C3, C4, C5, C6, and C7, with C1 closest to the skull. Below C7 begin the 12 thoracic vertebrae, called T1, T2, and so on, down to T12. Inferior to this are the five lumbar vertebrae—referred to as L1, L2, L3, L4, and L5—followed by the sacrum and coccyx.


C1 (Atlas)
C2 (Axis)
C3
C4
C5
C6
C7
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
Sacrum
Coccyx
7 Cervical vertebrae
12 Thoracic vertebrae
5 Lumbar vertebrae
Sacrum
Coccyx
Cervical curve
Thoracic curve
Lumbar curve
Sacral curve

Fulfilling the convention that bone names are often the basis for naming structures around them, such as nerves and vessels, the spinal nerves that exit between adjacent vertebrae through the intervertebral foramina are also named and numbered in a similar way as their corresponding vertebrae.

Cervical vertebrae are the smallest of the three types of vertebrae; they have a more petite vertebral body, and those bodies have a concave superior surface. Cervical vertebrae also typically have two prongs to their spinous processes, called a bifid spinous process. But the key feature that sets them apart from all other vertebrae is that cervical vertebrae have transverse foramina within their transverse processes. This series of openings transmit a vessel known as the vertebral artery that runs up the cervical spine and then enters the skull to help supply the brain with blood.

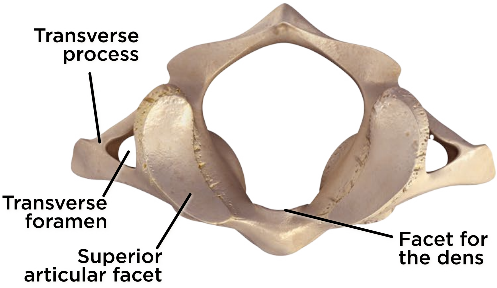
Like humans, giraffes also have seven cervical vertebrae. Theirs are just really tall!

Interestingly, in humans the transverse foramina of our seventh cervical vertebra are vestigial,* so our bilateral vertebral arteries skip C7 and jump into the transverse foramina of C6 as they pass superiorly toward the brain.

Each thoracic vertebra has several articulation sites for a pair of ribs. These are sometimes called costal facets because in medical terminology, *costo* means "rib." There are 12 thoracic vertebrae, and each articulates with a pair of ribs, so most people have a total of 24 ribs. In addition, the bodies of thoracic vertebrae go from a relatively small size following the cervical spine to a relatively large size as they approach the lumbar region. In fact, the size of the bodies of all vertebrae increases as you go from superior to inferior in the spine, at least above the sacrum, to help support the increasing amount of weight placed on each one.

The five lumbar vertebrae have large and boxy bodies and smaller transverse processes but larger spinous processes. Their superior and inferior articular processes are also larger. They lack transverse foramina and articulation sites for ribs since those are only found on cervical and thoracic vertebrae, respectively. The lumbar vertebrae don't have a specific feature of their own, other than their large size.

A few cervical vertebrae are unique. The first cervical vertebra, known as C1, is also called the atlas. Like in mythology, Atlas held up the world, and the atlas vertebra helps hold up our skull. It is unique in that it is the only vertebra without a vertebral body. It is basically just a large neural arch with a pair of transverse foramina on its lateral aspects. Its two superior articular facets are cup-shaped and join with a pair of matching convex facets at the base of the skull, forming one of the ellipsoidal or condyloid joints that sit like two spoons nesting together.



Atlas (C1)

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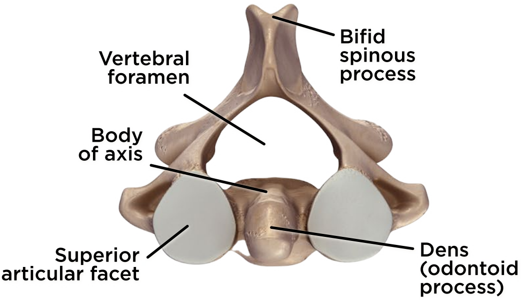
* This refers to an evolutionary feature that is no longer used.



Axis (C2)

The second cervical vertebra, C2, is known as the axis. It looks typical for a cervical vertebra, except that it has a projection on the superior surface of its body known as the dens, or odontoid† process.

The superior articular facets of C2 are quite flat, as are the matching inferior articular facets of C1. The dens of the axis forms an axis of rotation where it sits in the anterior aspect of the neural arch of C1. When you move your head right and left, the skull and the atlas rotate together around the dens on the superior surface of the axis. A connective tissue band called the transverse ligament on the atlas makes a sling around the dens to hold it in place.

When you nod your head yes, you're using the gliding motion of your skull on C1, among other vertebral movements. When you shake your head no, much of that rotation is happening between C1 and C2.

There are two types of joints that link most vertebrae to their adjacent buddies: cartilaginous joints formed by the intervertebral discs, and synovial joints between the inferior articular facets of one vertebra and the superior articular facets of the vertebra below it.

The joints between the articular facets are small but—like other synovial joints—have a joint cavity surrounded by a capsule that makes them freely movable. The joint where an intervertebral disc links two adjacent vertebrae are amphiarthrotic, meaning they offer just a bit of movement. And while they don't allow for a lot of motion, since the cartilage unites the inferior surface of one vertebral body to the superior surface of the body below it, the net effect of the stack of 24 vertebrae provides plenty of movement.

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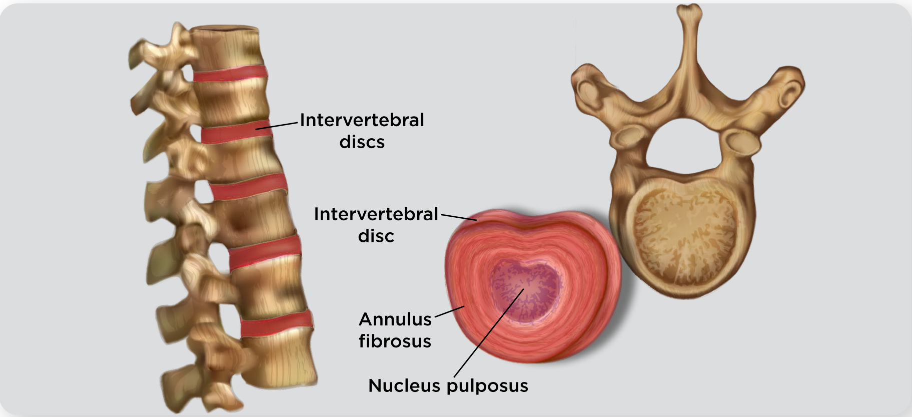
† *Odontoid* means "toothlike."



The intervertebral discs are composed of two kinds of material. The outer ring is made of fibrocartilage, which is a type of cartilage that's quite dense with collagen fibers. That ring is called the annulus fibrosus, and it surrounds a gel-like central region called the nucleus pulposus. The annulus fibrosus is tough cartilage that links the adjacent vertebral bodies together, while the jellylike nucleus pulposus acts like an inner shock absorber to help withstand compression due to weight placed on the spine.

Not only do the lumbar vertebrae, for example, support the weight of the upper body, but they also have to support the weight of anything we're carrying. So, the intervertebral discs increase in size, as do the vertebrae, from superior to inferior in the spine. And if the forces become too great—especially if the annulus fibrosus is dried out and brittle, as can happen with age—the nucleus pulposus can push through a tear in that outer ring of fibrocartilage. This is known as a herniated disc.

The Sacrum and the Coccyx

The last two elements in the vertebral column are the sacrum and the coccyx. The sacrum is quite different than the rest of the spine. It is a triangular bone typically made up of five former vertebrae. The sacrum has a body that is topped by an intervertebral disc that forms a cartilaginous amphiarthrotic joint with the inferior surface of the body of the fifth lumbar vertebra, L5. The sacrum also has a set of superior articular facets that join with the inferior articular facets of L5. So in that sense, the sacrum is like other vertebrae.

But rather than transverse processes, the sacrum has lateral masses that reach out toward joint surfaces that link the sacrum with the two pelvic bones. Instead of spinous processes, the sacrum has a median sacral crest running down its posterior surface.

Rather than having vertebral foramen, the sacrum has a canal down its midline that connects to openings on both the front and back of the sacrum, known as anterior and posterior sacral foramina, respectively. Ventral and dorsal rami come out of those openings to reach their targets. The sacral canal terminates in an opening called the sacral hiatus that can be palpated on the surface and used as a bony landmark for the administration of an epidural anesthetic. On the superior and anterior aspect of the sacrum is a forward projection called the sacral promontory, which is an important landmark in obstetrics.‡

The coccyx is the small tailbone that articulates with the sacrum; it is usually composed of three to four fused coccygeal vertebrae. So, while the spinal column starts with 33 vertebrae that ultimately fuse into 26 bones—seven cervical, 12 thoracic, and five lumbar vertebrae, plus a single sacrum and single coccyx—there are only about 23 or 24 total intervertebral discs. There isn't a disc between the skull and the atlas, nor between the atlas and axis, and there are only remnants of discs within the sacrum. Moreover, since the discs increase in size from the cervical spine to the lumbar spine, together they make up about 20% to 25% of the length of a person's spine.

When the vertebrae are stacked, most with intervertebral discs between them, the series is linked into the vertebral, or spinal, column. Notches at the pedicles of adjacent vertebrae leave a space between the bones called the intervertebral foramen. So, while each vertebra has a vertebral foramen posterior to its body, you can't find an intervertebral foramen on a vertebra. They are formed only when the vertebrae are stacked.

The vertebral foramina extend down the spinal column, forming a spinal cavity through which the spinal cord passes. Off that spinal cord come the spinal nerves that exit the vertebral column by passing laterally through the intervertebral foramina. Remember, the anterior and posterior roots of a spinal nerve are within the spinal canal and fuse to form a spinal nerve just before it exits its intervertebral foramen. Immediately after that, lateral to the intervertebral foramina, the spinal nerves divide into their dorsal and ventral rami.§

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‡ How far the sacral promontory projects anteriorly into the pelvis can determine whether a woman will likely be capable of a vaginal delivery or may need a cesarean section.

The adult spine has a slight *S* shape when viewed from the side. The net result helps maintain the proper center of gravity for upright posture and balance.

A series of ligaments connects adjacent vertebrae to help aid the stability of the spine. There's an anterior longitudinal ligament that is wide and strong and runs down the length of the stacked bodies of the vertebrae on their anterior side. And there's a narrow posterior longitudinal ligament that runs down the posterior aspect of the stacked vertebral bodies.

These ligaments reinforce the cartilaginous joints formed by the intervertebral discs and attach to the discs as well as the vertebrae they join. Other ligaments unite adjacent spinous processes, transverse processes, and laminae.

Reading

Biel, *Trail Guide to the Body*, ch. 4, "Spine & Thorax."

Dimon, *Anatomy in Action*, ch. 5, "Lengthened Support and the Healthy Spine."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 2, "Overview of Skeletal Anatomy."

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§ As you learned in the previous lecture, the dorsal rami are the distributional branches that supply the true back muscles and skin down the middle third of the back, while the ventral rami become intercostal nerves or braid into one of the plexuses: cervical, brachial, lumbar, or sacral.

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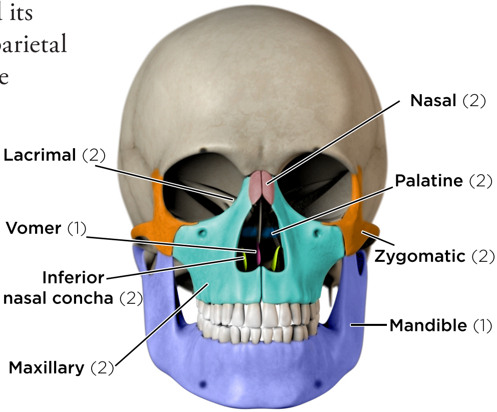
Lecture 8

THE SKELETON OF THE HEAD AND TORSO

Now that you have a good understanding of the spine, let's stack the skull on top of it. Then, we'll expand off the thoracic vertebrae to discuss the rib cage, and you'll also learn about the hyoid bone, a rather unique bone in the neck.

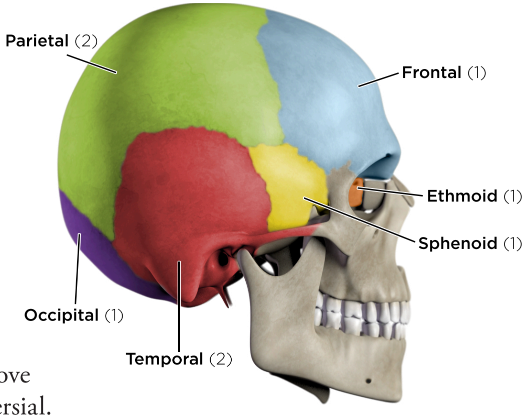
The Skull

The human skull is composed of 22 bones united by joints. It is typically divided into a cranial region, often called the braincase, and a facial region that surrounds most of our sensory openings. The cranial region includes eight bones that have the most direct relationship with the brain and its coverings. There are a pair of parietal bones that make up most of the dome or vault of the skull, a pair of temporal bones on either side of the skull, a single frontal bone in the forehead region, and a single occipital bone at the posterior skull.



The other two bones of the cranial region are a bit more obscure from an external view. One is the sphenoid bone, which is like an architectural buttress for the skull since it supports and joins with each of the other seven cranial bones. The final braincase bone is the ethmoid, and while it has the majority of its anatomy in the facial region, a projection of the ethmoid reaches up to the floor of the braincase, so that's where it is classified.

The facial skeleton is composed of 14 bones. There are a pair of zygomatic bones that make the prominences at the cheeks and a tiny pair of lacrimal bones in the eye sockets. A pair of nasal bones makes up the bridge of the nose, and a singular bone called the vomer helps make up the nasal septum that divides the nasal cavity in two. The pair of maxillary bones of the mid-face surround the nasal opening called the nasal aperture; these maxillae also form the upper jaw. The scientific name given to the unpaired lower jaw is the mandible. The remaining four bones are not readily seen externally: Two are the paired inferior nasal conchae on the sides of the nasal cavity, and a pair of L-shaped palatine bones likewise contribute to the lateral nasal wall but also help make up the roof of the mouth.



The majority of the joints in the skull are known as sutures. Many are interlocking at their edges, like teeth in a zipper. These are considered fibrous synarthrotic joints, which are immovable and are held together by connective tissue that is dense with fibers. Some practitioners claim that the bones of the skull move in adults, but that is controversial. However, the sutures between skull bones in the fetus do move: In fact, the fetal and newborn skull has fontanels, or soft spots, between some of the sutures that allow the actual overlap of cranial bones during the birth process, facilitating the journey through the birth canal. The sutures of the skull may completely close up with age.

There are names for all sutures of the skull, but only the larger sutures are covered in a basic anatomy course. The coronal suture is between the frontal and paired parietal bones; it sits across the crown of the head—which makes sense, since *coronal* means "crown." The sagittal suture runs between the two parietal bones, along the midsagittal plane. The lambdoid suture is posteriorly between the parietal bones and the occipital bone. Where the parietal bones intersect with the occipital bone, the result resembles an upside-down *V*, like the Greek letter lambda, which is why it's called the lambdoid suture.

The final major suture often mentioned in a basic anatomy course is the squamous suture found laterally between the temporal bone and the sphenoid and parietal bones. *Squamous* means "flat," and not only is this suture less squiggly or jagged than most other sutures, but it is also not an interlocking or serrate suture like the others. The squamous suture is considered a beveled or lap suture, where a pair of flat surfaces overlap.

> The sutures of the skull are somewhat protective in that they relieve some of the stress of a blow to the head.

Cranial sutures can have what are known as sutural bones or Wormian* bones within them. Some books call these ossicles—small islands of bone within the suture.

Another set of ossicles associated with the skull are the three tiny bones in the middle ear cavity within each temporal bone. They are named the malleus, incus, and stapes—translated as the hammer, anvil, and stirrup.

There are many, many skull landmarks. For instance, there are numerous foramina that provide entrance and exit for nerves and blood vessels. Some are only found inside the skull, while others are on its surface, or connect through and through. There are also plenty of muscle attachment sites—some to anchor muscles of facial expression and others, such as attachment sites at the base of the skull, for muscles that move the head and neck.

There are some skull landmarks that are important to movement and nerve supply. Let's start externally with some of the major openings. There is a supraorbital foramen or notch just above each eye orbit. In some people, it's a foramen, and in others, it's just a notch in the edge of the orbit roof. Below each orbit are corresponding infraorbital foramina. Also in vertical alignment with those are a pair of mental foramina in the mandible. This series of three bilateral openings transmits three paired branches of the fifth cranial nerve called the trigeminal nerve, along with their corresponding veins and arteries. These nerves are responsible for sensations from the facial skin.

The eye orbits contain several openings; the optic canal that transmits our optic nerve, which is the cranial nerve of vision; and a small artery that supplies structures in the orbit. There are also superior and inferior orbital fissures that transmit branches of other cranial nerves, including the motor nerves that supply muscles that move the eyeballs around.

Progressing laterally, there is an external auditory meatus on each side of the skull. A meatus is a tubelike passage in a bone; this is lined with skin and transmits sound waves into the eardrum. Posteriorly is the largest foramen in the skull—the foramen magnum—which transmits the brain stem, where it becomes the spinal cord, and also allows entrance of the vertebral arteries that ascend the neck through the transverse foramina of cervical vertebrae. On either side of foramen magnum are the occipital condyles that articulate with the first cervical vertebra.

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* These bones are named after the Danish physician Ole Worm.

At the base of the skull, there are many other openings, several of which transmit cranial nerves that provide sensation and motor control to structures mostly in the head and neck. Other passages are routes for blood vessels that need to enter the cranium. Some openings also transmit veins.

There are just as many openings inside the skull. These passages are also the means by which nerves and vessels communicate between the head and neck or relay our special senses (sight, smell, taste, hearing, and equilibrium†).

At the posterior aspect of the skull are nuchal lines on the occipital bone; these are the attachment sites for some true back muscles in the neck. Behind each ear, you can feel the bumps created by our mastoid processes, and there are styloid processes just medial to them. These landmarks are both on our temporal bones and are attachment sites for muscles of the neck. Two other bony landmarks at the base of the skull are the medial and lateral pterygoid‡ plates of the sphenoid bone.

There are differences between male and female skulls. On average, the bones of males are larger than females after puberty. Palpate your own skull and that of a different-sexed partner or good friend and see if you can identify any differences.

The pterygoid plates are attachments sites for muscles that help move the jaw. Laterally, the zygomatic arch—a bridge made partly of the zygomatic bone and partly by the temporal bone—can be easily felt passing posteriorly from the cheekbone. Laterally on the cranium, temporal lines stretch from the frontal bone to the parietal bone. The zygomatic arch and temporal lines are the origins for two major muscles of chewing.

The mandible has many bony landmarks, including for the insertions of the muscles that move it: The main portion of the jaw is the mandibular body, and the chin is called the mental protuberance.

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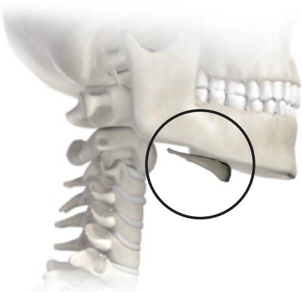
† Equilibrium is our special sense of balance maintenance, housed in the inner ear along with the sense of hearing.

‡ *Pter* means "wing," as in the winged dinosaurs called pterodactyls.

The angle of the jaw is located posteriorly, and the mandible's ramus projects superiorly to terminate in the coronoid process anteriorly and the mandibular condyle posteriorly. The condyle is also known as the head of the mandible, and just inferior to it is a constricted neck. The mandibular condyle articulates with the mandibular fossa on the temporal bone. This forms the only moveable joint of the skull, the temporomandibular (TMJ) joint.

The Hyoid Bone and the Rib Cage



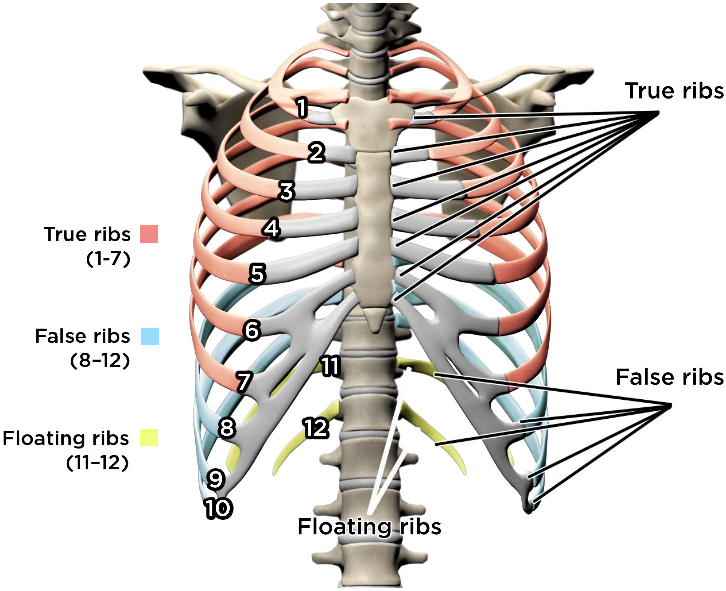
Inferior to the skull is the hyoid bone. It is unique within the skeleton because it is the only bone in the body that doesn't directly articulate with another bone. But it's not completely free-floating: It is attached to the cartilages of the larynx, or voice box, that sits inferior to it and is also attached to muscles of the neck, but it doesn't have a joint with any other bone.

The hyoid bone sits posterior and roughly parallel to the mandible. If you gently move the structures in your anterior neck from side to side for several seconds, you may begin to sense a pins-and-needles feeling at the base of your tongue. This is because the tongue is anchored to the hyoid bone.

The companion ribs of the thoracic vertebrae, covered in the previous lecture, and the sternum form the complex known as the rib cage. There are 12 thoracic vertebrae, and each is attached to a pair of ribs. Ribs have their own anatomical landmarks: Beginning posteriorly, there's the rib head, followed by a neck, and then a projection known as the tubercle. From the tubercle extends the shaft of the rib, which curves—in what's known as the rib's angle—as it passes from posteriorly to laterally and then anteriorly. On the inferior and deep or medial surface of the rib is the costal groove, in which intercostal nerves and vessels run. The sternal end of the rib is most anterior.

That's the anatomy of a typical rib, but not all ribs are created equally. For one thing, the ribs start out shorter in length, get longer, and ultimately shorten again. This results in a rib cage that is narrower superiorly and inferiorly and wider intermediately. The angles of the ribs also change in curvature through the rib cage. And while all ribs attach to the spine posteriorly, they do not all attach to the vertebral column in the same way.

In addition, not all ribs attach to the sternum anteriorly. The first seven pairs of ribs have their own costal cartilages that attach them to the sternum and thus are called true ribs. But rib pairs eight, nine, and 10 usually borrow the cartilage of rib seven to reach the sternum, and rib pairs 11 and 12 don't attach to the sternum at all. For this reason, pairs eight through 12 are known as false ribs, and pairs 11 and 12 are subgrouped as floating ribs.



Ribs don't just attach in one place to their respective vertebra; they attach in two places, which facilitates stability and movement. The head of a rib attaches to the body of a single thoracic vertebra, or it may span across the bodies of two thoracic vertebrae. In the superior and inferior portions of the rib cage, the rib head will attach to a single thoracic vertebral body, and the midrange ribs will attach to costal facets on two adjacent vertebrae, along with the intervening disc between them. Regardless, the tubercle of each rib attaches to the transverse process of the thoracic vertebra it corresponds to. These so-called costovertebral joints are gliding synovial articulations, so they are freely movable.

Related to this, remember that there are intervertebral foramina between adjacent vertebrae, and out of those come spinal nerves that almost immediately branch into dorsal and ventral rami for distribution to tissues. In the thoracic region, the ventral rami of those spinal nerves are called intercostal nerves and assume a simple pattern that hugs the inferomedial side of the ribs, running in the costal grooves on the deep surfaces of the ribs. These intercostal nerves have sensory components that govern segmental patches of skin on the thorax called dermatome patterns. But the intercostal nerves also supply the muscles of the rib cage as well as muscles of the anterolateral abdominal wall.

Reading

Biel, *Trail Guide to the Body*, ch. 5, "Head, Neck & Face."

Martini, *Martini's Atlas of the Human Body*, Head, Neck, Vertebral, and Thorax sections (cadaver images).

Ward, *Netter's Integrated Musculoskeletal System*, ch. 2, "Overview of Skeletal Anatomy."

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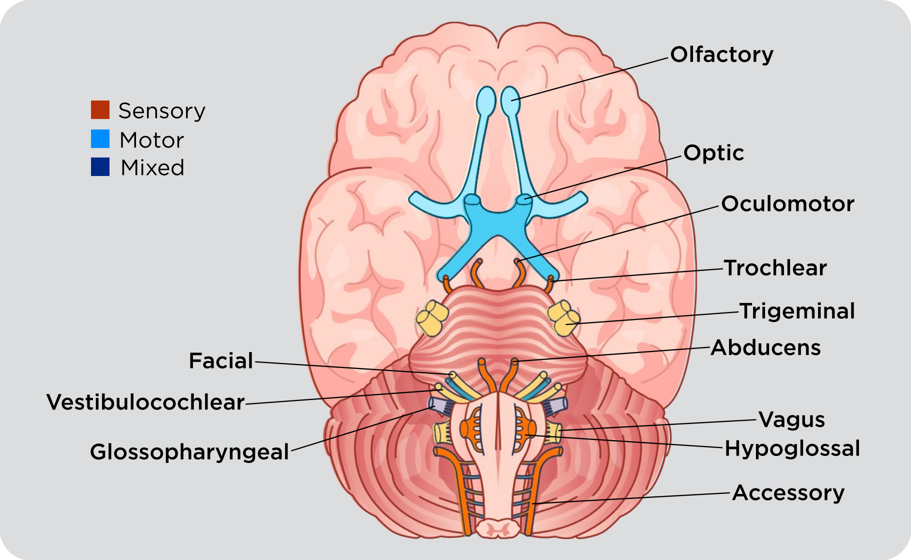
Lecture 9

THE MANY MUSCLES OF THE HEAD AND NECK

This lecture focuses on the muscles of the head and neck, what they do, and which cranial nerves innervate them.

The Cranial Nerves

The 12 pairs of cranial nerves supply most structures in the head and neck. Cranial nerves are designated with Roman numerals, I through XII, as they come off the brain from anterior to posterior. Cranial nerve I is the olfactory nerve, II is the optic nerve, III is the oculomotor, IV is the trochlear nerve, V is the trigeminal, VI is the abducens nerve, VII is the facial nerve, VIII is the auditory nerve, IX is the glossopharyngeal, X is the vagus nerve, XI is the spinal accessory, and XII is the hypoglossal.[*]


🟥 Sensory
🟦 Motor
■ Mixed
Olfactory
Optic
Oculomotor
Trochlear
Trigeminal
Abducens
Facial
Vestibulocochlear
Glossopharyngeal
Vagus
Hypoglossal
Accessory

There is a surprising number of small muscles throughout the head and neck. For example, there's a set of six muscles in each eye orbit—the socket containing the eyeball—that move the eye in complex patterns important to our sight. These are muscles of great precision but of little strength since their only job is to accurately coordinate movements between the two eyes for optimal vision.

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[*] One memory device for remembering the cranial nerves in order is "On Old Olympus's Towering Tops A Fin And German Viewed Some Hops."

Some of those muscles have an entire cranial nerve dedicated to them. In fact, of the 12 pairs of cranial nerves, two of the tiniest ones are solely devoted to controlling a single eye muscle each: cranial nerves IV (the trochlear nerve) and VI (the abducens nerve).

Another cranial nerve—number III, the oculomotor nerve—controls the other four muscles that steer the eyeballs, as well as the muscle that opens the upper eyelid. And while interesting and important, these so-called extraocular muscles are typically not a major focus of a musculoskeletal course.

There are also numerous tiny muscles within the soft palate—the fleshy portion of the posterior roof of the mouth—and many other muscles within the walls of the throat. Together, these aid in the voluntary phase of swallowing and in opening the eustachian tube to help equalize pressure in the middle ear, such as when you are subject to altitude changes in an airplane.

There are also many small muscles associated with the larynx, commonly called the voice box. These aid with breath holding and sound production. The vagus nerve, cranial nerve X, supplies most of these small muscles.

In the neck is a group of suprahyoid muscles that connect the hyoid bone to bones of the skull, as well as a group of infrahyoid muscles that connect the hyoid bone to the sternum, larynx, or pectoral girdle. The suprahyoid muscles elevate the hyoid bone and larynx during swallowing, and the infrahyoid muscles depress the hyoid bone and larynx. Most of the suprahyoid muscles are supplied by cranial nerves, but the infrahyoid muscles are more inferior in the neck and are supplied by nerves of the cervical plexus—a group of ventral rami off spinal nerves C1 to C4.

Also important to swallowing and speech, the tongue is essentially a group of muscles covered by mucous membrane, peppered with taste buds on its superior surface. The intrinsic muscles of the tongue give shape to the surface of the tongue, and extrinsic tongue muscles move the tongue in and out and left and right. Some muscles of the tongue originate on bones of the skull, such as the mandible or temporal bone; others take origin off the hyoid bone. Most muscles of the tongue are controlled by cranial nerve XII, the hypoglossal† nerve.

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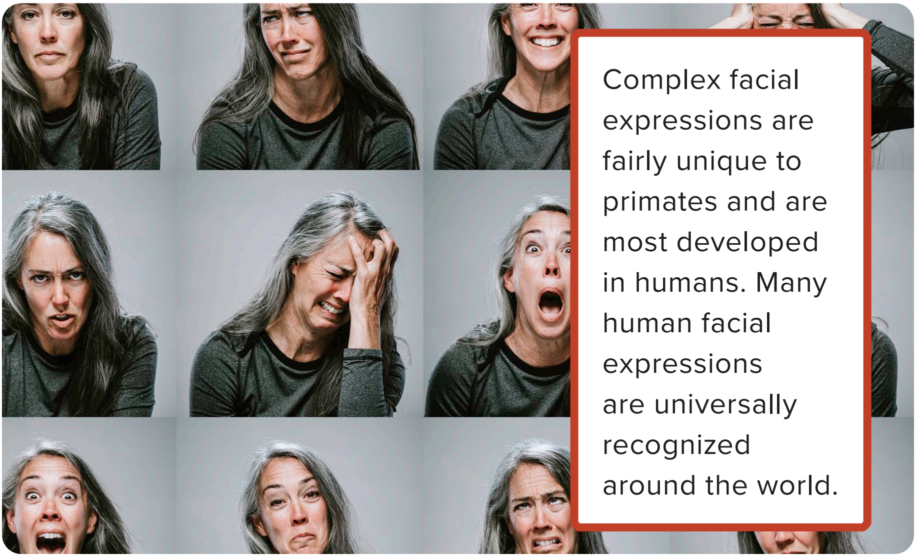
† *Glosso* means "tongue."

The two tiniest muscles in the body are inside the middle ear cavity—the tensor tympani and stapedius—and are attached to two of the small ossicle bones in the middle ear. These muscles aid hearing, as when the tensor tympani muscle contracts to protect us from loud sounds. The middle ear is a tiny chamber—an air-filled space that would hold just a few drops of fluid—but despite their close proximity, these two tiny muscles are each supplied by a different cranial nerve.

Muscles That Create Facial Expressions

Among the most interesting muscles in the entire body are those that create our facial expressions. These are unusual as muscles go, since while they originate on bone, most muscles of facial expression insert on the skin. So, rather than moving bones, these muscles steer the skin of the face around to result in a vast array of intricate patterns.

There are several main groups of facial muscles. Some muscles of facial expression are associated with the forehead and eyes, and there's a group around the mouth and some odds and ends between. And as a group, all muscles of facial expression are supplied by cranial nerve VII, the facial nerve.



Complex facial expressions are fairly unique to primates and are most developed in humans. Many human facial expressions are universally recognized around the world.

But the trigeminal nerve—cranial nerve V—provides sensations from the face. The name *trigeminal* implies its three main branches, and each one supplies sensations from a portion of the face. Its ophthalmic branch supplies skin of the forehead and down the nose, mainly by the supraorbital nerve; the maxillary branch supplies skin of the cheeks by the infraorbital nerve, in addition to being sensory to the upper teeth; and its mandibular branch supplies skin of the chin and lower face, mainly by the mental nerve, and is also sensory to the lower teeth. These come out the supraorbital, infraorbital, and mental foramina studied in the previous lecture. So facial skin is covered by a different cranial nerve than our facial muscles.

Regarding the complex around the eyes, the frontalis muscle runs vertically within the skin above the eyes and wrinkles the forehead. The corrugator supercilii‡ muscle draws the eyebrows together, wrinkling or corrugating them. A circular muscle called the orbicularis oculi, an orb-shaped sphincter-like muscle, encircles each eye. It causes squinting when we use the peripheral fibers but causes blinking or closure of the eyelids when we use the portion within the eyelid.

Around the mouth is another circular muscle called the orbicularis oris,§ the muscle that puckers the lips. Along either side of the nose is a vertical muscle called the levator labii¶ superioris, which elevates the upper lip. The risorius is a horizontal muscle that can pull the corners of the mouth posteriorly. These two—levator labii superioris and risorius—fuse with the edges of orbicularis oris, so not all of these muscles insert on the skin. Some actually attach to each other.

Two other muscles that relate to the orbicularis oris include the zygomaticus major, which is our smiling muscle that originates from the zygomatic bone at the prominence of the cheek and passes inferomedially to fuse with orbicularis oris. Its counterpart is the *depressor anguli oris*, a name that means "to depress the angle of the mouth," as in frowning. Inferior to the mouth is the mentalis; it's a deeper muscle that protrudes the lower lip, as in pouting.

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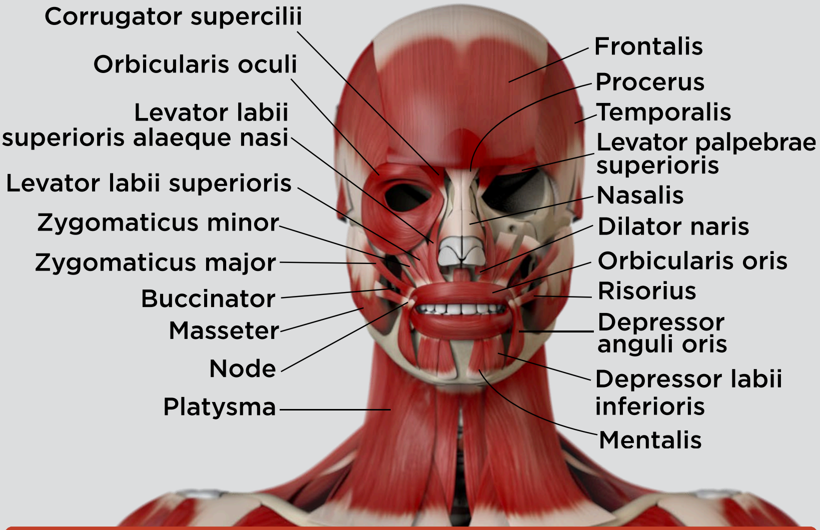
‡ *Cili* is used to refer to some structures of the eye.

§ This comes from *oral*, meaning "mouth."

¶ *Labium* means "lip."


Corrugator supercilii
Orbicularis oculi
Levator labii superioris alaeque nasi
Levator labii superioris
Zygomaticus minor
Zygomaticus major
Buccinator
Masseter
Node
Platysma
Frontalis
Procerus
Temporalis
Levator palpebrae superioris
Nasalis
Dilator naris
Orbicularis oris
Risorius
Depressor anguli oris
Depressor labii inferioris
Mentalis

Textbooks and other sources invariably list different collections of the facial muscles, and in this case, not only is the naming of these a human construct, but even the differentiation of these into individual muscles is a human construct, as most are not discrete entities.

Another deep muscle associated with the oral region is called the buccinator, which is contained within the cheek wall and is used to draw in our cheek wall, as in sucking through a straw, or to compress and expel air within the oral cavity, such as when blowing a trumpet. In addition, the buccinator is important to eating; along with the tongue, it helps continually reposition food for chewing, instead of having the food get stuck in the furrows between our cheeks and our gums.

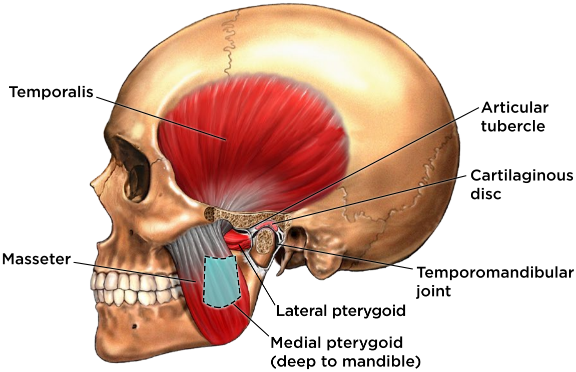
There are a few remaining members of the facial expression group that are not really associated with the face at all. One is the occipitalis, which is like a horizontal band at the very back of the scalp. Surprisingly, it's connected to the frontalis muscle of the forehead by a broad, flat tendon called an aponeurosis, and that tendon is one of the layers of the scalp. So despite its position, the occipitalis is part of the complex of subcutaneous muscles supplied by the facial nerve. An additional muscle, the platysma, is within the skin of the neck. Sometimes it's called the shaving muscle, because it can tighten the skin of the neck, as may be done while shaving. Like occipitalis, platysma is also supplied by the facial nerve.

Humans also have auricularis muscles deep to the skin around the ears. These muscles move and rotate the ears of cats, dogs, horses, and many other mammals in the direction of sound. But in most people, the auricularis muscles are vestigial remnants of our animal evolution—though you might know somebody who can wiggle their ears. If so, they are doing it using their facial nerve.

Estimates of people who can wiggle their ears range between about 10% to 20%, and some sources say it's a learnable action.

Other Major Head and Neck Muscles

Another group of important head and neck muscles are the muscles of *mastication*, meaning "chewing." These four pairs of muscles operate the only diarthrotic synovial joints in the skull, the paired temporomandibular joints (TMJs). These are joints between the head, or condyle, of the mandible and the mandibular fossa on the temporal bone. By shape, they are combination hinge-and-gliding joints: hinge for the opening-and-closing action and gliding for side-to-side and front-to-back actions. A cartilaginous disc between the bones aids in keeping the mandible in place by deepening and cushioning the mandibular fossa, while the articular tubercle on the inferior aspect of the zygomatic arch helps keep the mandible from anterior displacement.



Two paired muscles that help us close our jaw and clench our teeth are the temporalis and masseter muscles. The temporalis sits on either side of the head at the temple—hence the name—and if you clench your teeth, you can feel it tensing. The masseter is more associated with the mandible itself, and if you put your fingers on the sides of your jaw while clenching your teeth, you can feel it work.

The temporalis has a broad origin along the temporal lines on the sides of the skull and inserts on the coronoid process of the mandible. The masseter originates along the zygomatic arch and has a large insertion along the lateral ramus of the mandible.

The two other pairs of muscles that act on the TMJ are the medial pterygoid and lateral pterygoid. Both are located deep to the mandible and originate on the pterygoid plates of the sphenoid bone. They insert on the deep surface of the mandible, so neither pterygoid muscle can be easily seen without removing part of the ramus of the mandible to expose an area known as the infratemporal fossa. Both the medial and lateral pterygoids can aid in side-to-side movements of the jaw, as when performing grinding actions between molar teeth. This is also sometimes called lateral excursions of the mandible.

Both pterygoids are also involved with protraction of the mandible—which means pushing the jaw out anteriorly—while retraction of the mandible is accomplished by the posterior fibers of the temporalis muscle pulling the jaw back into place. Despite their location in and around the face, muscles of the jaw are not facial expression muscles and are not supplied by the facial nerve. All muscles of chewing are supplied by cranial nerve V, the trigeminal nerve. Its third branch, the mandibular nerve, exits the cranial cavity to reach the infratemporal fossa, and this control of mandibular movements is one of the reasons for its name.

Within the neck, there's a group of muscles known as the scalenes that originate on the transverse processes of cervical vertebrae and insert on the first and second rib. They flex the neck when used bilaterally, but if just one side is used, the result is flexion to the same side as the muscle used (ipsilateral action).

However, because the scalenes are attached to the first couple of ribs, if we keep our neck stationary, a really deep breath can allow the scalenes to raise the first few ribs. This is how we fill the very top, or apex, of the lungs, which are in the root of the neck. The scalenes are so close to the midline of the body, where spinal nerves emerge from their intervertebral foramina, that there really isn't a name for their nerve supply. Small so-called segmental branches off the cervical plexus simply directly enter the scalene muscles.

> Because gravity can open the jaw, it's often part of standard embalming procedure to wire the upper and lower jaw together.

Finally, the sternocleidomastoid muscle is named for its dual origins on the sternum and clavicle and its insertion on the mastoid process of the temporal bone (the bump felt just behind the ear). Because the sternocleidomastoid passes anterior to the vertebral column, when we contract both muscles, we flex our neck. But when just one sternocleidomastoid is used, it slightly flexes the neck and turns the face to the opposite side of the muscle used (contralateral action). Though it is a muscle of the neck, the sternocleidomastoid is supplied by cranial nerve XI, the spinal accessory nerve. That cranial nerve supplies only one other muscle: the trapezius, which is posterior to the vertebral column.

Reading

Biel, *Trail Guide to the Body*, ch. 5, "Head, Neck & Face."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 4, "Muscles of the Face and Head"; ch. 5, "Muscles of the Neck."

Dimon, *Anatomy in Action*, ch. 3, "Extensors and Head Balance."

Jarmey, *The Concise Book of Muscles*, ch. 3, "Muscles of the Scalp and Face"; ch. 4, "Muscles of the Neck."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 3, "Muscles of the Face and Head"; ch. 4, "Muscles of the Neck."

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Lecture 10

BACK MUSCLES: LAYERING AND MOVEMENTS

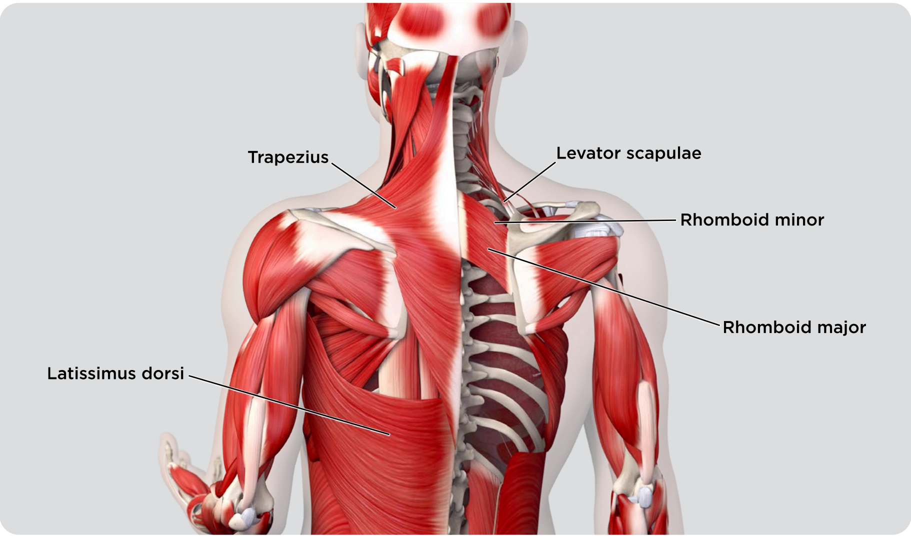
In terms of complexity, the back muscles are just as complicated as the spine. There are a great number of muscles in the back—so many, in fact, that they are considered in layers, mostly related to their functions.

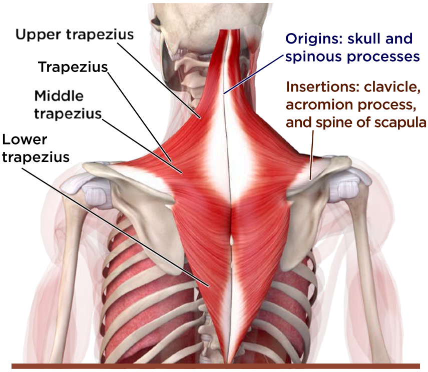
The So-Called Back Muscles

The first group of muscles to introduce are not really back muscles at all—they are muscles of the upper limb that happen to live on the back. Muscles cross a joint to cause movement at that joint, and with all muscles of the limbs, the origin is always proximal and the insertion is always distal.

The first collection of so-called back muscles are called the appendicular muscles of the back because they take origin off the axial skeleton—either the spine or skull—for the anchorage they need to gain their leverage. And they move some aspect of the upper appendage, so their insertion is either on the scapula or clavicle or directly on the humerus. There are generally considered to be five of these superficial or appendicular back muscles: the trapezius, latissimus dorsi, rhomboid major, rhomboid minor, and levator scapulae.

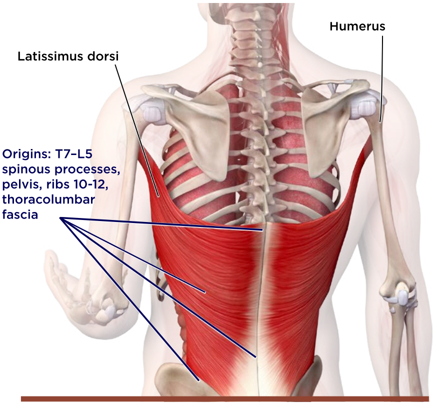
Back pain affects an estimated 80% of people at some time in their lives. It is among the most common reasons cited for lost workdays and trips to the doctor.




Upper trapezius
Trapezius
Middle trapezius
Lower trapezius
Origins: skull and spinous processes
Insertions: clavicle, acromion process, and spine of scapula

The trapezius—sometimes called the trap—has a long origin, from the base of the skull all the way down through the thoracic vertebrae, taking origin along the midline of the spine, from the spinous processes of cervical and thoracic vertebrae. It inserts on the spine of the scapula and around to the lateral clavicle; together the scapula and clavicle are called the shoulder girdle or pectoral girdle. The trapezius is a good example of a muscle with a complex shape—somewhat like a trapezoid—and as a consequence, it has complex and even contradictory actions.

The upper region of the trapezius elevates the shoulder girdle, whereas the lower fibers are used to depress the shoulder girdle—as when you're sitting on the floor and use your hand to help push yourself up. The middle fibers retract the scapula, pulling them together, an action that some references call adducting the scapula. But because the trapezius attaches to the posterior skull, it can also extend the head and neck. The trapezius is supplied by the same nerve that serves the sternocleidomastoid muscle: the spinal accessory* nerve, cranial nerve XI.


Humerus
Latissimus dorsi
Origins: T7–L5 spinous processes, pelvis, ribs 10-12, thoracolumbar fascia

The latissimus dorsi is another muscle *on* the back that isn't a muscle *of* the back: It has its belly on the dorsal side of the trunk, originating from a layer of broad, flat connective tissue called the thoracolumbar fascia. The latissimus dorsi muscles—sometimes called the lats—insert on the anterior and proximal part of the humerus. Since the latissimus dorsi is posteriorly located, it has several jobs. It extends the shoulder, and since it crosses the axilla, or armpit, it also adducts the humerus toward the body. Finally, because it attaches anteriorly, it can turn the humerus medially—as in rolling it inward, toward the body.

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* What puts *accessory* in its name is that some branches from the cervical plexus assist, or "accessorize," this cranial nerve.

The spine as an entity moves in many ways: flexion, or forward bending; extension, or the erect posture that is a key function of the true back muscles; lateral bending, also aided by the true back muscles when only one side is used; and rotation, which is a function that the transversospinalis can assist abdominal muscles in performing.

The other three superficial or appendicular muscles of the back are the levator scapulae, which, as its name indicates, elevates the scapula by originating on the transverse processes of some cervical vertebrae and inserting on the superior aspect of the scapula. It works with the upper fibers of the trapezius to shrug the shoulders. And both the rhomboid major and rhomboid minor retract the scapulae in conjunction with the middle fibers of the trapezius. The rhomboids do this generally by originating on the spinous processes of thoracic vertebrae and inserting on the medial border of the scapula. Their slightly oblique orientation also lets them elevate the scapula and rotate it so that the shoulder joint faces inferiorly.

The rhomboid major is larger and more inferior, attaching inferior to the spine of the scapula, while the rhomboid minor is smaller but more superior, usually at and slightly above the spine of the scapula.

The next set of muscles that live on the back consists of two nearly paper-thin muscles that are often called the intermediate or respiratory back muscles, even though recent studies suggest that they don’t have much, if any, role in respiration. These are the serratus posterior superior, located deep to the rhomboids, and the serratus posterior inferior, located deep to a small region of the latissimus dorsi. Like some other muscles very much involved in respiration, the serratus posterior superior and inferior are supplied by ventral rami of thoracic nerves, known as intercostal nerves.

The True Back Muscles

Continuing deeper brings us to the real action in the back: the true back muscles. These are muscles that act on the spine, not the upper limb or the rib cage. And, with extremely few exceptions, these muscles are supplied by dorsal rami of spinal nerves, not ventral rami like the so-called respiratory muscles or the appendicular muscles, which are supplied by the ventral rami of the brachial plexus. Recall that dorsal rami are the branches of spinal nerves that supply true back muscles, and ventral rami are spinal nerve branches that serve all other muscles of the trunk and limbs—or at least any muscle not supplied by a cranial nerve, like the trapezius is.

True back muscles are a complicated and overlapping collection of muscles located posterior to the spinal column that act on the spine. As a group, these muscles are known as the axial muscles of the back, since their origins and insertions are on bones of the axial skeleton. Sometimes they are called the intrinsic muscles of the back. *Intrinsic* means that a muscle's origin, insertion, and action are all in the same body part. They are also called the deep back muscles, as compared to the superficial appendicular muscles or the intermediate respiratory muscles, but the naming gets confusing, since even these deep, or true, back muscles come in layers.

> There's not much movement between any two adjacent vertebrae, but stacking 24 of them allows the accumulation of slight rotations between adjacent pairs, adding up to a much greater range of motion within the spine as a whole.

The true back muscles can be subdivided into four main layers: the splenius† complex, the erector spinae group, the transversospinalis group, and an even deeper group called segmentals. There are even a few additional groups of back muscles, too.

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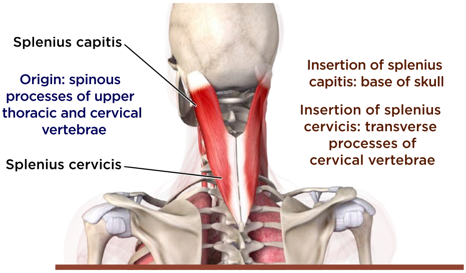
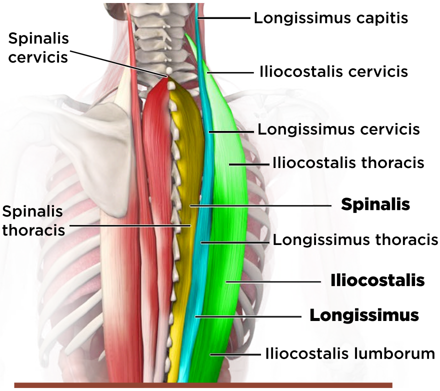
† *Splenius* means "plaster," like an old term for "bandage"; early anatomists must have thought the pair of muscles looked like a bandage on the neck.


Splenius capitis
Origin: spinous processes of upper thoracic and cervical vertebrae
Splenius cervicis
Insertion of splenius capitis: base of skull
Insertion of splenius cervicis: transverse processes of cervical vertebrae

The first set of true back muscles are the splenius capitis and splenius cervicis. As the names imply, the splenius capitis attaches to the skull, while the splenius cervicis attaches to the transverse processes of cervical vertebrae. The splenius complex is found only in the neck and has a continuous origin along the spinous processes of upper thoracic and cervical vertebrae. When acting together, the splenius capitis and cervicis extend the head and neck; when acting unilaterally, they aid lateral flexion and head rotation to the same side, which is ipsilateral action.


Spinalis cervicis
Spinalis thoracis
Longissimus capitis
Iliocostalis cervicis
Longissimus cervicis
Iliocostalis thoracis
Spinalis
Longissimus thoracis
Iliocostalis
Longissimus
Iliocostalis lumborum

The next group, or layer, of true back muscles is collectively called the erector spinae muscles, since they help keep the spine straight. These constitute the bulk of the large longitudinal blocks of muscle that can be felt on either side of the spine. Because of their differential development in various areas of the back, as well as for their different insertions, anatomists subdivided them longitudinally into three subunits.

The iliocostalis group is the most laterally located; the longissimus group is intermediately located; and the spinalis is most medially located, adjacent to the spinous processes of the vertebrae.[‡] Iliocostalis[§] is the part of the erector spinae that goes from the ilium of the pelvis up to ribs. Longissimus goes the long way—all the way from the low back up to the skull. Spinalis is the part of the erector spinae group that is most well developed in the thoracic region, sitting closest to the spine.

[‡] To help remember the names, from lateral to medial, think of the phrase "I Like Standing"—since these muscles help keep the spine upright—where the *I* is for *iliocostalis*, the *L* is for *longissimus*, and the *S* is for *spinalis*.

[§] *Costal* means "pertaining to the rib."

The third major group of true back muscles is the transversospinalis. These muscles are so named because they connect transverse and spinous processes of vertebrae. Each transversospinalis muscle originates on the transverse process of one vertebra and inserts on the spinous process of another. As a result, they have an oblique orientation, as they cross one or more intervertebral joints. Since they are posterior to the vertebrae, they extend, support, and stabilize the spine, but their oblique orientation also allows them to have a role in rotation of the spine.

Transversospinalis is a group name, and like the erector spinae, these muscles are subdivided into three subunits: the semispinalis, the multifidus, and the rotatores. These are tucked in the relatively narrow trough between spinous processes and transverse processes, so rather than being considered from lateral to medial, these subunits are discussed in layers, from superficial to deep. In general, the semispinalis muscles of the transversospinalis group span five or more vertebral segments, while the multifidus are deep to them and span three to five vertebral levels. The deepest members of the transversospinalis group are the rotatores that span just one or two vertebral levels.

In addition to the splenius muscles in the neck, the erector spinae that run the length of the spine, and the transversospinalis group, there is a fourth set of muscles along the spine that's generally called the segmental complex, as these muscles span just one vertebral segment. These are subdivided into the interspinales muscles, a tiny pair of muscles that run between adjacent spinous processes, and the intertransversarii muscles that connect adjacent transverse processes.

All of the true back muscles up to this point are supplied by the dorsal rami of spinal nerves. However, relatively recent studies have demonstrated that the intertransversarii are supplied by ventral rami.

Reading

Biel, *Trail Guide to the Body*, ch. 4, "Spine & Thorax."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 6, "Muscles of the Torso."

Delavier, *Strength Training Anatomy*, ch. 4, "Back."

Dimon, *Anatomy in Action*, ch. 6, "The Spinal Musculature of the Trunk."

Jarmey, *The Concise Book of Muscles*, ch. 5, "Muscles of the Trunk."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 5, "Muscles of the Trunk."

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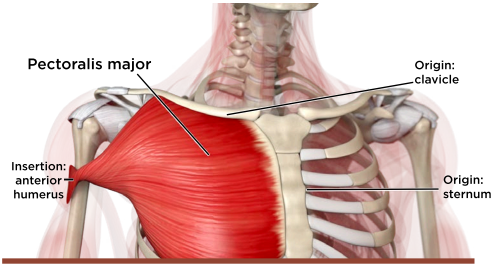
Lecture 11

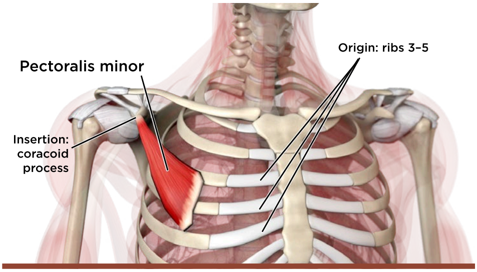
TORSO MUSCLES: THORACIC, ABDOMINAL, AND PELVIC

As you learned in the previous lecture, some of the back's superficial muscles are actually muscles of the upper limb. Several muscles on the anterior and lateral chest are also upper limb muscles—specifically, the pectoralis major and minor, the serratus anterior, and the subclavius. These aren't designed to move the bones of the thorax; rather, they move the arm or the pectoral girdle—either the scapula or clavicle.

The Upper Limb Muscles

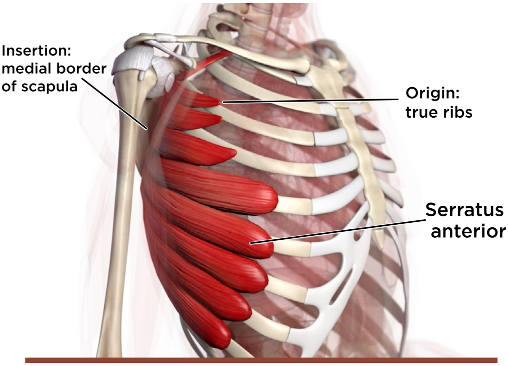

Pectoralis major
Origin: clavicle
Insertion: anterior humerus
Origin: sternum

The pectoralis major muscles—often called the pecs—take origin from the sternum and clavicle and insert on the anterior humerus. Because the pectoralis major is located anteriorly, it flexes the humerus. Also, because it crosses the axilla, the pectoralis major adducts the upper limb, pulling it toward the body. And since it attaches to the anterior side of the proximal humerus, the pectoralis major acts in medial or inward rotation, rolling the head of the humerus toward the body.


Pectoralis minor
Origin: ribs 3–5
Insertion: coracoid process

The pectoralis minor, on the other hand, originates entirely on the axial skeleton—typically on ribs three, four, and five—and inserts on the coracoid process of the scapula. The pectoralis minor mainly acts to stabilize and depress the scapula.

So both pectoralis muscles act on the upper limb; their actions are not on the chest itself. The medial and lateral pectoral nerves off the brachial plexus supply them.

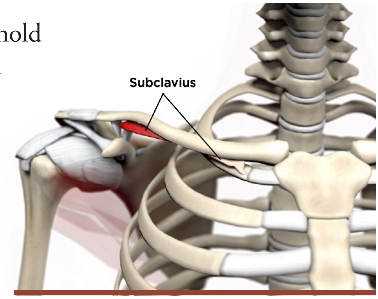

Insertion: medial border of scapula
Origin: true ribs
Serratus anterior

The serratus anterior is a muscle of the lateral chest wall, and as its name implies, it has a serrated, or jagged, origin—mostly off of the true ribs (the first seven ribs). It inserts on the deep and medial border of the scapula and is supplied by the long thoracic nerve off the brachial plexus.

As an antagonist to the rhomboids—which retract the scapulae, drawing them together—the serratus anterior pulls the scapulae apart, often called protraction or occasionally abduction. It also holds the scapula to the rib cage and can rotate the scapula to allow the upper limb to reach past the horizontal plane.

The subclavius is a tiny muscle that helps hold the clavicle to the first rib and gets its own tiny branch of the brachial plexus as its nerve supply.

Because the pectoralis major, pectoralis minor, serratus anterior, and subclavius are all upper limb muscles, they are supplied by branches of the brachial plexus.



The Cervical Plexus

The cervical plexus is a network formed by the ventral rami of the first cervical nerve (C1) through the fourth cervical nerve (C4). The C1 nerve comes out between the skull and the atlas; the C2 nerve comes out between the atlas and the axis. The C3 nerve comes out above the third cervical vertebra, and the C4 nerve comes out between the C3 and C4 vertebrae. In other words, ventral rami of cervical nerves emerge above their corresponding bone.

The ventral rami of the first four cervical nerves, C1 through C4, form a braided network on each side. As all spinal nerves are paired, all plexuses are bilateral as well.

The cervical plexus has several cutaneous nerves—nerves that reach the skin—that emerge off of it. Though cutaneous nerves have multiple functions, they primarily take sensory information from the peripheral nervous system toward the central nervous system for interpretation. The four main cutaneous branches of the cervical plexus are the great auricular nerve, the transverse cervical nerve, the lesser occipital nerve, and a group of supraclavicular nerves.*

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* These are named for their different receptive areas of the skin, from which they head toward the central nervous system, carrying sensory information.

In addition to cutaneous branches, the cervical plexus also has two important motor branches: One is a unique structure called the ansa cervicalis.† This is made from the ventral ramus of C1 that connects with the joined ventral rami of C2 and C3, forming a loop-like complex of nerve branches. Together, tiny branches off of this loop supply most of the infrahyoid muscles and carry C1 ventral rami fibers to one of the four suprahyoid muscles.

The diaphragm is only found in mammals.

The other major motor branch off the cervical plexus is called the phrenic nerve. It is a combination of the ventral rami of cervical nerves C3, C4, and C5. This is a vital nerve that travels from the cervical plexus down through the thorax by clinging to the pericardial sac around the heart. Together, the right and left phrenic nerves supply the respiratory diaphragm. The diaphragm is a shelf of skeletal muscle that separates the thoracic cavity from the abdominopelvic cavity and thus is a rare example of skeletal muscle that's inside of and spans our ventral body cavity, rather than being outside of, or in the walls of, a body cavity.

The respiratory diaphragm is also unusual in that it's a muscle that inserts on itself. It has fibers originating from inside the rib cage all around the thoracic wall, almost like the spokes of a wheel. Its insertion is a large median area of the muscle known as its central tendon. When the diaphragm is at rest, it is dome-shaped, and the muscle fibers are relaxed, but when our brain stimulates the phrenic nerves, which in turn stimulate the diaphragm, the muscle fibers shorten and the dome shape of the diaphragm goes flat. This increases the vertical dimension of the thoracic cavity, and when volume increases, pressure decreases, so air rushes into the lungs following this high- to low-pressure gradient.

In the average person and for a typical inhale, the lungs hold about 500 milliliters of air, which is the volume of a standard disposable water bottle.

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† This is Latin for "loop of the neck."

Another unusual aspect of the diaphragm is its rhythmicity. It is skeletal muscle, but it's programmed for regular contractions and relaxations—whether we're asleep or even unconscious. Yet it is still voluntary skeletal muscle, since we can choose to inhale or exhale at any time. We don't have other skeletal muscles that have such rhythmic contractions and relaxations like the diaphragm. This normal, quiet, diaphragmatic breathing is known as our tidal volume, since air comes in and out like the tide, with barely perceptible movements of the chest wall.

Deep breaths—whether in or out—require chest wall muscles known as the intercostals. As the name implies, the intercostal muscles travel between and connect the ribs. There are three main layers to these muscles of the rib cage: the external intercostals, the internal intercostals, and the innermost complex of chest wall muscles.

The external intercostals have their fibers oriented down and in—or, in anatomical terms, from superolateral to inferomedial. The external intercostals can elevate the ribs for forceful inhalation. When this happens, the rib cage expands in a lateral or horizontal direction, further increasing its volume and thereby decreasing its pressure, so even more air rushes in.

The internal intercostals have their muscle fibers perpendicular to the external intercostals; in other words, the internal intercostal fibers are oriented in a superomedial to inferolateral direction. Because of this, the internal intercostals can pull the ribs together during exhalation or expiration. So, during forced exhalation, your ribs are pulled together, decreasing the volume of the chest. When the chest volume decreases, the air inside the lungs is put under increasing pressure, so air is forcefully expelled. We can also recruit our abdominal muscles to expel even more air.

Even some neck muscles, such as the sternocleidomastoid and the scalenes, can help when someone takes a really deep breath. Some of the neck muscles can raise the upper ribs and sternum to bring air into the topmost areas of the lungs. Even the pectoralis minor muscles, which normally move the scapula, can be recruited to help raise the upper ribs.

The innermost complex of chest muscles—the deepest layer—consists of three subcomponents. On the deep side of the anterior rib cage is the transversus thoracis muscle. It's an almost star-shaped muscle that attaches the deep side of some anterior ribs to the posterior side of the sternum.

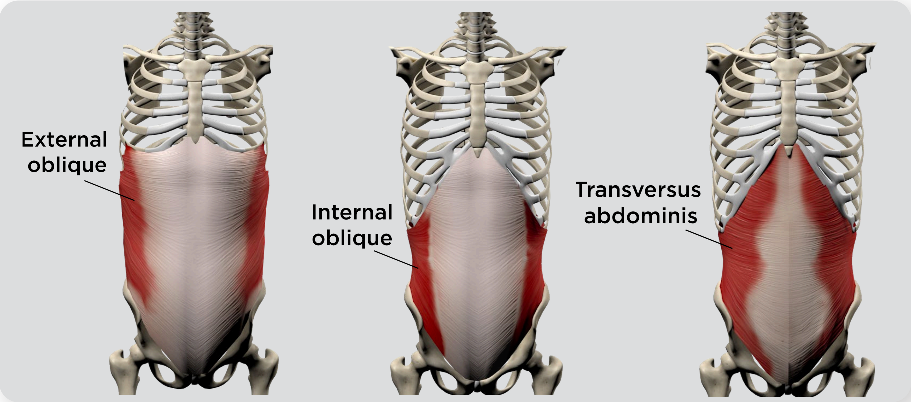
The transversus thoracis is said to aid deep expiration. Then, laterally are the innermost intercostals, which have roughly the same fiber direction and function as the internal intercostals. The third member of the innermost complex is found on the deep side of the ribs posteriorly; these are called the subcostales or subcostal muscles. These posterior muscles are still inside the rib cage, but unlike the innermost intercostal muscles, the subcostales span two ribs, not just one. There's also a group of muscles called the levatores costarum, which are on the posterior side of the ribs—deep to the erector spinae but lateral to the transverse processes. They are supplied by dorsal rami yet, as their name implies, can also elevate the ribs to aid deep inspiration.

The Abdominal Wall Muscles

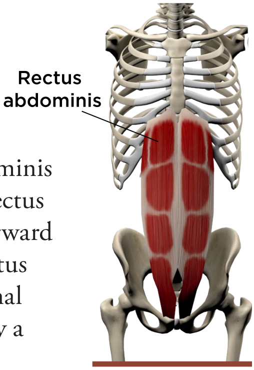
The abdominal wall muscles—or abs—are comprised of the external oblique, internal oblique, transversus abdominis, and rectus abdominis. Anatomically and developmentally, these are a continuation of the pattern seen in the intercostal muscles. In fact, the fiber directions of the external and internal oblique muscles in the abdominal wall match those of external and internal intercostals.

In addition, like the transversus thoracis of the innermost layer of the chest wall, the deepest layer in the abdominal wall is the transversus abdominis. It's as if the pattern continues—we just run out of ribs. But in places where they both occur, the abdominal wall muscles superficially overlap the intercostals.

The external oblique muscles originate on the lower eight ribs, and like the external intercostals, they also have their fibers down and in. The internal oblique muscles have their fibers perpendicular, or down and out, similar to the internal intercostals. The internal oblique and transversus abdominis both originate on the thoracolumbar fascia of the back—the hip bones—and from an inferior structure called the inguinal ligament, which you can think of as the rolled hem of the abdominal wall muscles. The transversus abdominis also takes part of its origin off the costal cartilages of the lower ribs, and as its name implies, it has muscles fibers in a transverse direction.



We have no anterior bones from the sternum to the pubic bone, so the external oblique, internal oblique, and transversus abdominis muscles all insert on their companion muscle of the other side. This reinforced midline is called the linea alba.‡ These three more laterally placed abdominal wall muscles reach that midline linea alba by large, flat tendons called aponeuroses; they only have muscle fibers laterally in the body wall.



The final muscle of the anterolateral abdominal wall, the rectus abdominis, is encased in the aponeuroses of the other three paired abdominal muscles, forming the so-called rectus sheath around the rectus abdominis muscle. The fibers of the rectus abdominis are vertically oriented, and this rectus sheath aids the rectus abdominis in its key role of flexing the spine, as in a forward bend. This is partly because the anterior part of the rectus sheath—made of the aponeuroses of the other abdominal muscles—is attached to the rectus abdominis muscle by a series of transverse bands of connective tissue.

These are called the tendinous intersections of the rectus abdominis muscle and are what give well-muscled people that so-called six-pack look to their anterior abdomen.

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‡ This is Latin for the "white line."

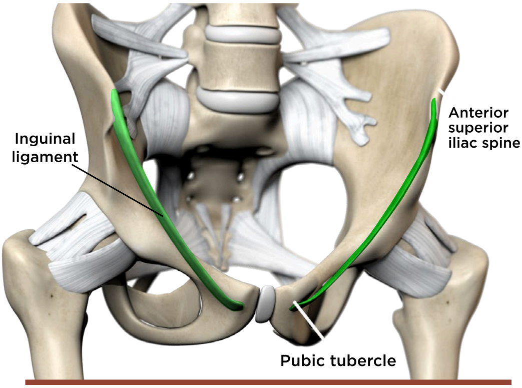
In addition to flexing the spine, the rectus abdominis shares one function with the other three abdominal wall muscles: compression of the abdomen. This action aids in childbirth, defecation, or forced exhalation, since compressing the abdomen can force the abdominal cavity contents inferiorly or push the diaphragm more superiorly into the thorax. But compression of the abdominal wall is the only function that all four abdominal muscles share, and it is the only function of the transversus abdominis, the deepest of these.

Due to its orientation and midline insertion, the external oblique can also cause contralateral rotation of the spine. This means that when the left muscle is used, it turns the right side of the torso, including the right shoulder, toward the midline. On the other hand, the internal oblique engages in ipsilateral rotation, meaning that you use the right one to turn the right side of the body toward the midline.

The directionality of the fibers of the left external oblique and the right internal oblique is the same, so when we turn our right shoulder to the midline, we are using our left external oblique along with our right internal oblique.

The abdominal wall muscles are primarily supplied by intercostal nerves, the ventral rami of thoracic nerves. When it comes to the most inferior reaches of the abdominal wall musculature, down by the inguinal ligament, the first lumbar nerve also gets involved.

The inguinal ligament, the rolled hem of the oblique muscles, is not a true ligament but rather the conjoined edges of the external oblique, internal oblique, and transversus abdominis. The inguinal ligament extends from the anterior superior iliac spine—the prominence that most people call their hip bone—and attaches anteriorly to the pubic tubercle, a bump on the pubic bone of the pelvis. In people with well-developed musculature and little body fat, it can often appear as a band in the crease between the torso and the thigh.



The Pelvic Region

In addition to the respiratory diaphragm, we have two other shelves of skeletal muscle that span regions of other body cavities: the pelvic diaphragm and the urogenital diaphragm.

The pelvis is a ring-type bony structure composed of the two hip bones and the sacrum and coccyx. The pelvic diaphragm, or pelvic floor, is a funnel-shaped group of muscles that closes off the large passageway through the pelvis to support our pelvic organs, especially the tail end of the digestive tract. In fact, the rectum and anal canal are essentially the outlet of this funnel-shaped diaphragm. The pelvic diaphragm—subcomposed of the levator ani and coccygeus muscles, both made of voluntary skeletal muscle—fuses with the smooth muscle in the walls of the digestive tract to help ensure that the terminal part of the digestive tract doesn't prolapse through the pelvic floor.

The other shelf of skeletal muscle in the pelvic region is the urogenital diaphragm. It sits just inferior to the funnel-shaped pelvic diaphragm anteriorly and supports the urinary and reproductive outlets—which pass through an anterior opening in the pelvic diaphragm known as the urogenital hiatus.§ The urogenital outlets are one in the same in males, as the male urethra is a combined urinary and reproductive passageway, but are separate in the urethra and vagina of females. After these urinary and reproductive outlets come through the hiatus in the pelvic diaphragm, they are supported at a more inferior level by the urogenital diaphragm.

Reading

Biel, *Trail Guide to the Body*, ch. 4, "Spine & Thorax."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 6, "Muscles of the Torso."

Delavier, *Strength Training Anatomy*, ch. 3, "Chest"; ch. 7, "Abdomen."

Dimon, *Anatomy in Action*, ch. 4, "Flexors and Front Length"; ch. 7, "Breathing."

Jarmey, *The Concise Book of Muscles*, ch. 5, "Muscles of the Trunk"; ch. 6, "Muscles of the Pelvis and Perineum."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 5, "Muscles of the Trunk."

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§ A hiatus is a natural gap in a body structure.

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Lecture 12

DIGITAL CADAVER LESSON: HEAD, NECK, AND TORSO

This is a digital lecture that reviews what has been covered in lectures 7 through 11 using the Anatomage Table to move three-dimensionally through the human body. Watch the video to look beneath the skin and aid your understanding.

Reading

Herbert, Heisler, Chinn, Krabbenhoft, and Malakhova, *A Photographic Atlas for Anatomy & Physiology*, ch. 3, "The Skeletal System"; ch. 4, "The Muscular System" (cadaver images).

Martini, *Martini's Atlas of the Human Body*, Head, Neck, Vertebral, Thorax, and Abdomen sections (cadaver images).

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. B, "Trunk Wall."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 9, "Clinical Anatomy of the Back"; ch. 12, "Clinical Anatomy of the Torso."

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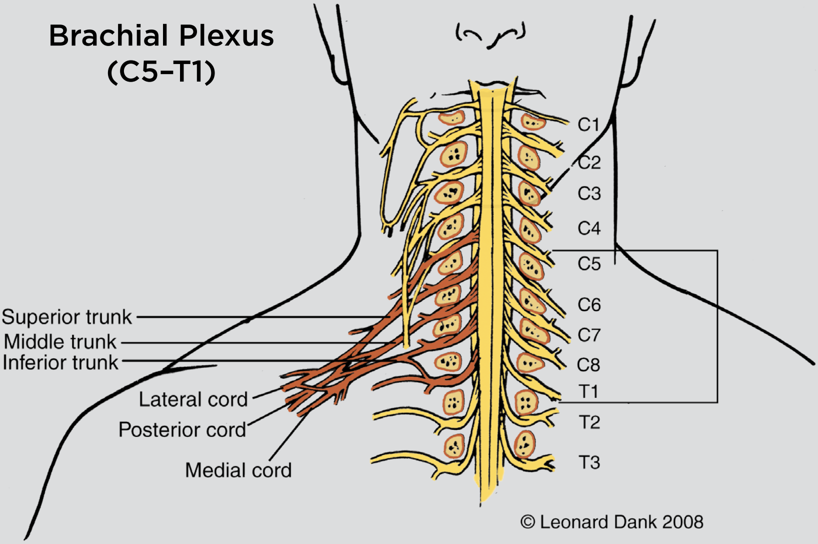
Lecture 13

THE BRACHIAL PLEXUS OF THE UPPER LIMB

The brachial plexus sets the stage for the study of the upper limb because it spans from the innervation of upper limb muscles of the shoulder all the way down to the muscles that control the fingers. In addition, the brachial plexus takes nearly all the sensations of the upper limb to the central nervous system for perception.

Components of the Brachial Plexus

The brachial plexus—where *plexus* is Latin for “braid” or “plait”—is a braided network of five ventral rami, starting with the fifth cervical nerve (C5) to the ventral ramus of the first thoracic nerve, known as T1. Ventral rami of thoracic spinal nerves can either be intercostal nerves or engage in a plexus. T1 does both: Part of it hugs the first rib as the first intercostal nerve, but the rest of it enters into the brachial plexus to help supply the upper limb.


Brachial Plexus
(C5–T1)
Superior trunk
Middle trunk
Inferior trunk
Lateral cord
Posterior cord
Medial cord
C1
C2
C3
C4
C5
C6
C7
C8
T1
T2
T3

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There are eight cervical nerves: C5 comes out above, or superior to, the fifth cervical vertebra; the C6 nerve comes out above the sixth cervical vertebra; C7 comes out above the last cervical vertebra; and C8 comes out below, or inferior to, the C7 vertebra. Then, from the first thoracic nerve down, all spinal nerves except the sacral nerves and coccygeal nerve come out below their bone of the same number. So the final nerve that contributes to the brachial plexus, T1, emerges from below the first thoracic vertebra.

But either because it is more complex than any other plexus of the somatic nervous system or because it is seemingly more integral to our humanity and day-to-day tasks, the brachial plexus braiding itself is broken down into regional subcomponents. From proximal to distal, parts of the brachial plexus braiding are referred to as roots, trunks, divisions, cords, and branches. (One of the mnemonics* that can help you remember this is "Read That Darn Cadaver Book.") All this complexity occurs in the root of the neck and the relatively protected anatomical region known clinically as the axilla, commonly called the armpit.

Confusingly, the roots of the brachial plexus are actually ventral rami. The use of the term *roots* here does not refer to the dorsal and ventral roots that come off the spinal cord and merge to form a spinal nerve. When talking about the brachial plexus, the ventral rami of spinal nerves C5 to T1 become the origins—in other words, the roots—of the plexus itself. In this case, the roots of the plexus are the ventral rami of spinal nerves C5, C6, C7, C8, and T1.

As for the trunks of the brachial plexus, the ventral rami of C5 and C6 merge, forming what's called the *upper* trunk of the brachial plexus—though better anatomical terminology would be *superior*. The ventral ramus of C7 stays on its own to form the middle trunk of the brachial plexus. And the ventral rami of C8 and T1 braid together, forming what's called the *lower* trunk of the brachial plexus—though *inferior* would be a better anatomical name for it.

Each spinal nerve is a bundle of axons: the transmitting part of a neuron. Nerves, by definition, are bundles of these axons traveling together outside the central nervous system. So, when the ventral ramus of C5 and ventral ramus of C6 merge, their axons are not changing; they are being rebundled into a single, new grouping of the axons in the two original ventral rami. The axons from C5 are still from C5, and those from C6 are still from C6. The fibers don't change their nature; they just change their pathway. So the upper trunk is made of C5 and C6; the middle trunk is unbraided, so it is still C7; and the lower trunk is made of C8 and T1 combining but not changing their nature.

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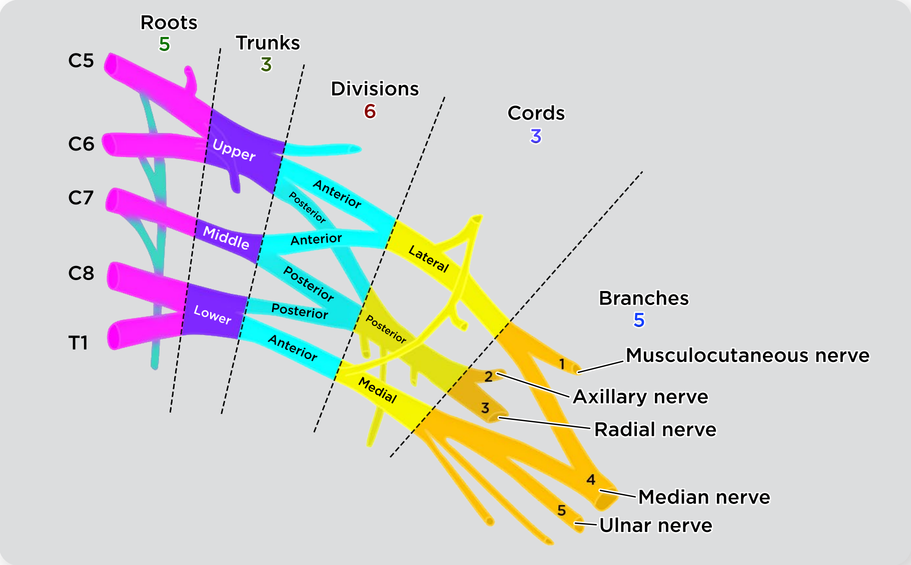
* Mnemonic devices, which help you remember a series of items or concepts, are everywhere in the sciences—especially in anatomy and other health sciences. Whole books have been written about medical mnemonics, which have helped many students get through courses that require lots of memorization.


Roots
5
Trunks
3
Divisions
6
Cords
3
Branches
5
C5
C6
C7
C8
T1
Upper
Middle
Lower
Anterior
Posterior
Anterior
Posterior
Posterior
Anterior
Lateral
Posterior
Medial
1
2
3
4
5
Musculocutaneous nerve
Axillary nerve
Radial nerve
Median nerve
Ulnar nerve

The next anatomical facet of the brachial plexus is that each of the three trunks splits into an anterior division and a posterior division. What's actually happening is the braided axons in the upper trunk that came from the ventral rami of spinal nerves C5 and C6 are being split into an anterior division and a posterior division. Likewise, the ventral ramus of C7—the middle trunk—is being split into an anterior division and a posterior division. And the lower trunk that is now a combination of the ventral rami of spinal nerves C8 and T1 is being distributed into an anterior and posterior division.

The anterior divisions travel anterior to the axillary artery—a major artery of the body that carries blood into the upper limb—and the posterior divisions pass posterior to the axillary artery. So at this point, the braiding of the brachial plexus makes a cage of sorts around the axillary artery.

Moving distally along the plexus, all three of the posterior divisions—the one from the upper trunk, the one from the middle trunk, and the one from the lower trunk—merge to form the posterior cord. The anterior division from the upper trunk and the anterior division from the middle trunk merge to form the lateral cord. The anterior division from the lower trunk stays on its own to form the medial cord.

So the three cords are lateral, medial, and posterior. Up to this point, the braiding was happening in the neck and then the axilla. But if you consider the outstretched arm, which these cords are now entering, the lateral cord is on the thumb side of the upper limb, which is lateral, and the medial cord is on the little finger side, which is the upper limb's medial aspect. The posterior cord is deep in the axilla, traveling to the posterior aspect of the upper limb.

> The upper limb is foundational to much of our humanity. Even if other animals had the brains and language abilities that we have, they simply do not have the manual dexterity.

At this cord level, the last of the braiding or combining of axons is reached. Now the three cords divide to form the branches of the brachial plexus. But these so-called branches are actually the five main nerves that result at the end of the braiding. Sometimes these are referred to as terminal branches, since they are the termination of the plexus—just like the origins of the plexus were called roots.

Calling them terminal branches makes it sound like they are finished, but these nerves all have muscular and sensory branches of their own. When the word *terminal* is applied to these nerves off the brachial plexus, it simply means that the plexus as a network is now complete. The braiding is done. The five resulting nerves supply muscles from the shoulders to the fingertips in the upper limb; in fact, every muscle within the limb itself is supplied by one or two of these nerves.

The posterior cord divides into two nerves. One is the axillary nerve that stays in the shoulder region and supplies two muscles: the deltoid and the teres minor. The other branch off the posterior cord is the much larger radial nerve. The radial nerve is a major nerve that supplies all muscles of the posterior upper limb—both the arm region (the area between the shoulder and elbow) and the posterior forearm. The radial nerve contains axons from all ventral rami of the plexus, since it is off the posterior cord, which is a braid of all posterior divisions from each of the trunks.

The lateral cord and the medial cord each send a branch toward the midline of the plexus, and the resulting nerve is known as the median nerve. This results in a *Y*-like appearance, in which the two "arms" of the *Y* are the contributions from the lateral and medial cords and the stem of the *Y* is the median nerve. Recall that *median* refers to the midline of a structure, and this median nerve comes off the approximate midline of the brachial plexus's more anterior components: the lateral and medial cords. The median nerve supplies most of the muscles in the anterior forearm and some muscles in the palm of the hand.

The remainder of the lateral cord—after its contribution to the median nerve—continues as the musculocutaneous nerve, which supplies the three muscles of the anterior arm, including the biceps brachii. The remainder of the medial cord, after giving off its contribution to the median nerve, continues as the ulnar nerve, which supplies a few muscles in the anterior forearm and most muscles in the palmar hand.

Nerves That Supply Muscles in Other Areas

The five terminal branches are just the main nerves that come off the plexus and head down the upper limb. But there are plenty of muscles that help move the upper limb that aren't necessarily located on—or at least don't originate in—the limb itself. So, all along its braiding, the brachial plexus gives off numerous nerves to supply muscles that move the scapula, for example, and live on the back or chest or in the shoulder. These small nerves—that supply only one, two, or maybe three muscles each—come off at the brachial plexus's root level, trunk level, or cord level.

For instance, the long thoracic nerve comes off at the root level—that is, off of the ventral rami of C5, C6, and C7—and supplies only the serratus anterior muscle. The dorsal scapular nerve also leaves the plexus at the root level and supplies the levator scapulae, rhomboid major, and rhomboid minor. All of these muscles live on the back or on the chest, even though their job is in the upper limb. Two nerves come off at the trunk level—specifically off the upper trunk. The nerve to the subclavius supplies the subclavius muscle, and the suprascapular nerve supplies two muscles that are part of the shoulder group known as the rotator cuff: the supraspinatus and infraspinatus.

Off the posterior cord come three nerves: the upper subscapular nerve, the lower subscapular nerve, and the thoracodorsal nerve between them. The upper subscapular nerve only supplies the subscapularis muscle, another of the rotator cuff muscles. The lower subscapular nerve also supplies the subscapularis but additionally serves the teres major. The thoracodorsal nerve supplies only the latissimus dorsi muscle, one of the muscles in the superficial appendicular group on the back.

Finally, the medial pectoral nerve comes off the medial cord and supplies both the pectoralis major and pectoralis minor. The lateral pectoral nerve comes off the lateral cord and supplies only the pectoralis major. So, the pectoralis major gets two nerves—the medial and lateral pectoral nerves—while the pectoralis minor gets only the medial pectoral nerve.

The brachial plexus supplies nearly all muscles that operate the scapula, the clavicle, or any part of the upper limb. In fact, the only muscle of the upper limb not supplied by the brachial plexus is the trapezius, governed by the spinal accessory nerve, a cranial nerve. But none of these nerves reach the skin; they only supply muscles on the chest or superficial back or around the shoulder region.

There are two other nerves off the medial cord of the brachial plexus, and these only supply skin, not any muscles. These are the medial brachial cutaneous nerve, also known as the medial cutaneous nerve of the arm, and the medial antebrachial cutaneous nerve, which is also called the medial cutaneous nerve of the forearm. These are the only two nerves directly off the brachial plexus that solely supply skin, but all of the terminal branches—axillary, radial, musculocutaneous, median, and ulnar nerves—have cutaneous branches. These are the reason that the dermatomes of the upper limb are C5, C6, C7, C8, and T1.

Reading

Herbert, Heisler, Chinn, Krabbenhoft, and Malakhova, *A Photographic Atlas for Anatomy & Physiology*, ch. 5, “The Nervous System” (cadaver images).

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. C, “Upper Limb.”

Ward, *Netter’s Integrated Musculoskeletal System*, ch. 4, “Innervation of the Muscle Compartments”; ch. 10, “Clinical Anatomy of the Upper Limb.”

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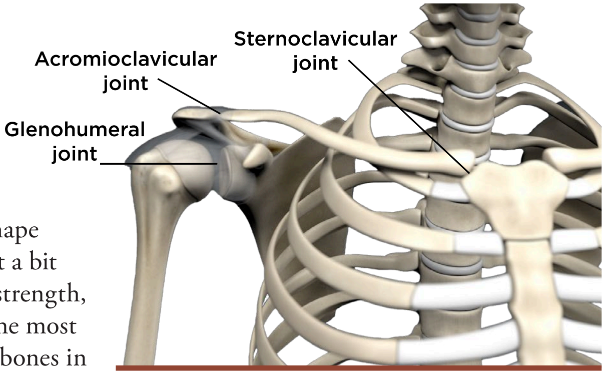
Lecture 14

THE SHOULDER: MOBILITY VERSUS STABILITY

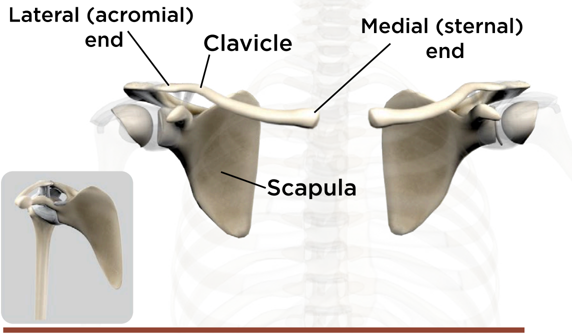
The shoulder is the most mobile joint in the human body. The shoulder region is actually a complex of joints: the sternoclavicular (SC) joint, where the collarbone meets the manubrium of the sternum; the acromioclavicular (AC) joint, where the clavicle meets the scapula; and the true ball-and-socket joint between the humerus and the scapula.

The Bones of the Shoulder

The two bones of the pectoral girdle are the clavicle and scapula. The clavicle is a relatively simple bone with a knobby medial end that you can feel at the top of your sternum. Then, you can feel that it has a slight curvature anteriorly and then swoops back posteriorly, ending in a flatter lateral end. This *S* shape of the clavicle gives it a bit more resiliency and strength, but it is still one of the most frequently fractured bones in the body.



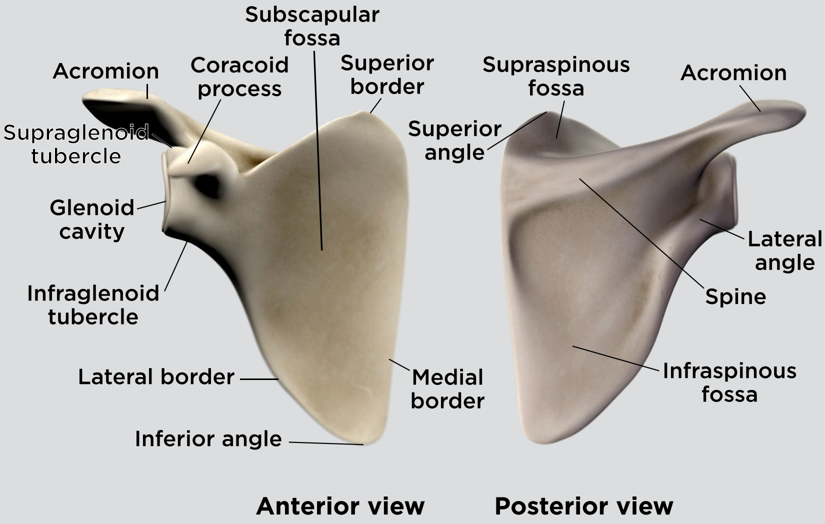
One key reason for this vulnerability is that the joint where the medial end of the clavicle articulates with the manubrium of the sternum is the only place that the entire upper limb is jointed to the axial skeleton. Though there are 30 bones in the upper limb, as well as two bones in the pectoral girdle, the only place that our entire upper limb has a bony joint with the axial skeleton is at that SC joint.



The SC joint contains a cartilaginous disc, which provides a bit of cushioning when a force is applied to the lateral shoulder. There are also several ligaments: an interclavicular ligament that bridges the two clavicles along the superior aspect of the sternum; an anterior and posterior SC ligament on the front and back aspects of the joint, respectively; and a costoclavicular ligament that holds the clavicle to the first rib for added stability. The combined result of this anatomy is slight but multidirectional movements at the SC joint.

The scapula is a relatively freewheeling and quite moveable bone. But regardless of how it may look in an image of a skeleton, the scapula has no bony articulation with the vertebrae or the ribs. Another reason the scapula is so mobile is because of the many muscles that either insert or originate there. The scapula is a relatively thin bone that's roughly triangular in shape. It has a superior border, a medial or vertebral border, and a lateral or axillary border. The triangle shape results in a superior, inferior, and lateral angle to the bladelike body of the scapula.

The anterior surface is relatively flat and is called the subscapular fossa, since it's deep to the scapula, facing the posterior rib cage, but there's an anterior projection at the superior end of the anterior scapula known as the coracoid process. Posteriorly, an easily felt landmark called the spine of the scapula expands laterally into the acromion process. Above the scapular spine is a depression called the supraspinous fossa, and inferior to the spine is a larger depression called the infraspinous fossa. Lateral to the scapular spine is the socket known as the glenoid cavity or glenoid fossa. A small bump above the glenoid cavity is the supraglenoid tubercle, and a small bump just below the socket is the infraglenoid tubercle.


Subscapular fossa
Acromion
Coracoid process
Superior border
Supraglenoid tubercle
Glenoid cavity
Infraglenoid tubercle
Lateral border
Inferior angle
Medial border
Superior angle
Supraspinous fossa
Acromion
Lateral angle
Spine
Infraspinous fossa
Anterior view
Posterior view

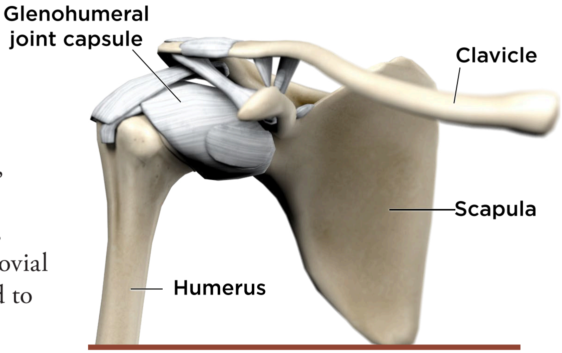
It's the flatter, lateral end of the clavicle, sometimes called its acromial end, that articulates with the scapula at the AC joint—that's the shelf of bone you feel at the prominence of your shoulder. This is a synovial joint, but it is a simple gliding joint, where the AC ligament unites the two bones of the pectoral girdle.

> The shoulder has the greatest range of motion of all of our joints. Even the most trained gymnasts cannot do with their hip joints what they can do with their shoulders.

Other ligaments support the joint, including a coracoclavicular ligament and a coracoacromial ligament. As its name implies, the coracoclavicular ligament unites the coracoid process of the scapula to the clavicle. The coracoacromial ligament doesn't unite two different bones but bridges two processes on the same bone; it serves as a tether that holds the supraspinatus tendon in position.

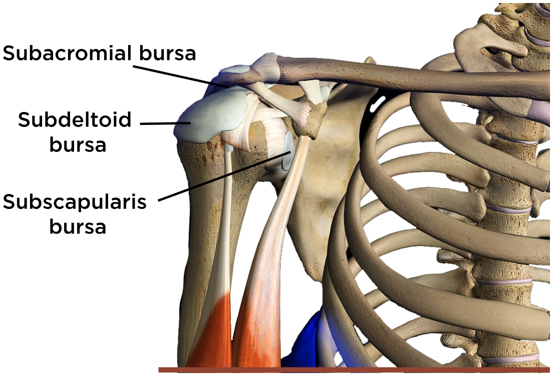
The glenohumeral joint is where the real shoulder mobility happens. This is where the rounded head of the humerus articulates with the shallow glenoid cavity of the scapula. Ball-and-socket joints are multiaxial joints at which flexion and extension occur, such as when the humerus swings forward and back; where abduction and adduction occur, as when the humerus is drawn away from and then back toward the body; and where medial and lateral rotation occur, as when the head of the humerus is rolled inward or outward. The combination of all these movements in sequence is known as circumduction—which only happens at ball-and-socket joints.

The glenohumeral joint is surrounded by a joint capsule made of connective tissue; the capsule is loose inferiorly to facilitate full abduction of the upper limb, as when pointing to the sky. Like other diarthrotic joints, this capsule is lined by a synovial membrane that secretes fluid to lubricate the joint.



Another feature that promotes such a full range of shoulder motion is the shallow nature of the glenoid fossa; this relatively flat structure facilitates the multidirectional movements of the humeral head. A structure called the glenoid labrum is a cartilaginous expansion that increases the surface area of the glenoid fossa but doesn't really deepen it.

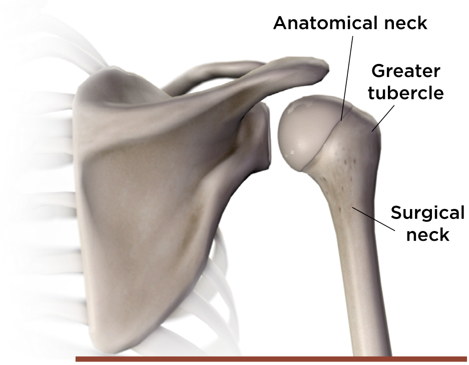
There are several ligaments deep to the anterior portion of the capsule—a superior, middle, and inferior glenohumeral ligament, named for the structures they connect and also their positions relative to each other. But the posterior aspect of the shoulder joint capsule is reinforced by three of the four rotator cuff muscles, while the fourth rotator cuff muscle helps the glenohumeral ligaments reinforce the anterior part of the shoulder joint. All this contributes to some degree of stability while still allowing great mobility at the shoulder.



There are several bursae around the shoulder joint, including the subacromial bursa between the acromion process of the scapula and the tendon of the supraspinatus muscle. That bursa often communicates with another bursa, the subdeltoid bursa, deep to the deltoid muscle. There's also a subscapularis bursa beneath the subscapularis muscle, and that is one of the synovial pockets that's continuous with the synovial membrane lining of the shoulder joint itself.

With regard to limb muscles, the origin is always proximal and the insertion is always distal, so some shoulder muscles that originate on the back, chest, or scapula insert on the proximal humerus. Adjacent to the head of the humerus, there's a greater tubercle that projects laterally and a lesser tubercle that projects anteriorly. Between them is the intertubercular groove, also known as the bicipital groove, since the tendon of the long head of the biceps brachii muscle passes through it.

The humerus also has two "necks": One is called the anatomical neck, which is the slight constriction immediately adjacent to the head of the humerus, since a head is usually followed by a neck. But there's also what's called a surgical neck; it is the narrowed region distal to the tubercles where the shaft of the humerus forms.



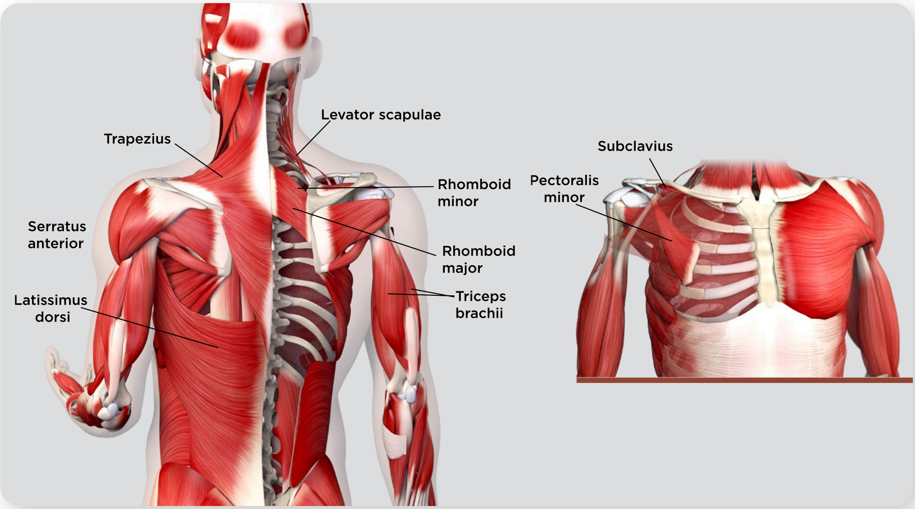
The Muscles of the Shoulder

There are many muscles that govern shoulder movements. Some shoulder muscles move the scapula or the clavicle, whereas others move both. Many of these can also serve as fixators that anchor the scapula in place against the chest wall so that muscles that originate on the scapula can move the humerus.

There is a group of seven muscles that attach some part of the axial skeleton to the shoulder girdle: the trapezius, levator scapulae, rhomboid major, rhomboid minor, serratus anterior, pectoralis minor, and subclavius. What links these together is that they originate on the axial skeleton—which here includes the skull, ribs, or vertebrae—and insert on the clavicle, scapula, or both.

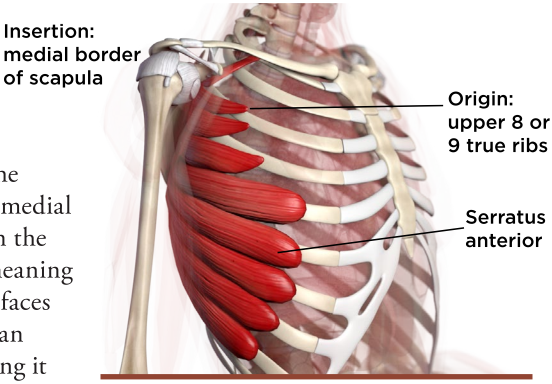
> A fractured clavicle can't be casted, though there are braces to help immobilize the shoulder to facilitate healing.

Trapezius originates from the skull and the spinous processes of cervical and thoracic vertebrae, and it inserts on the lateral third of the clavicle, the acromion process of the scapula, and along the scapular spine. The upper fibers of trapezius elevate the pectoral girdle, the middle fibers retract or adduct the scapula, and the lower fibers depress the pectoral girdle. The trapezius muscle's innervation is unusual in that it is supplied by a cranial nerve, cranial nerve 11, the spinal accessory nerve.

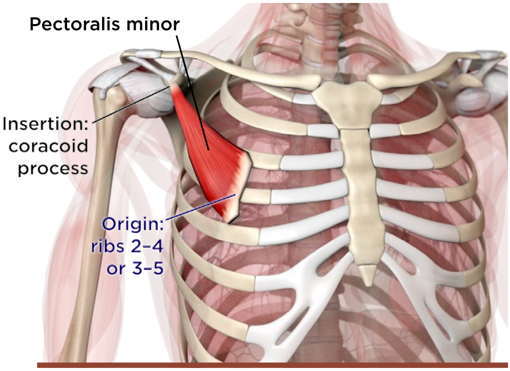

Levator scapulae
Trapezius
Rhomboid minor
Serratus anterior
Rhomboid major
Latissimus dorsi
Triceps brachii
Subclavius
Pectoralis minor

Levator scapulae takes origin off the transverse processes of C1 to C4 and inserts on the medial or vertebral border of the scapula, above the scapular spine. As a result, levator scapulae elevates the scapula and can rotate it in such a way as to point the glenoid cavity inferiorly. But if other muscles hold the scapula in place, levator scapulae can also flex the neck laterally. It is supplied by the dorsal scapular nerve off the roots of the brachial plexus. Levator scapulae shares that nerve with rhomboid major and rhomboid minor, which both originate off spinous processes.

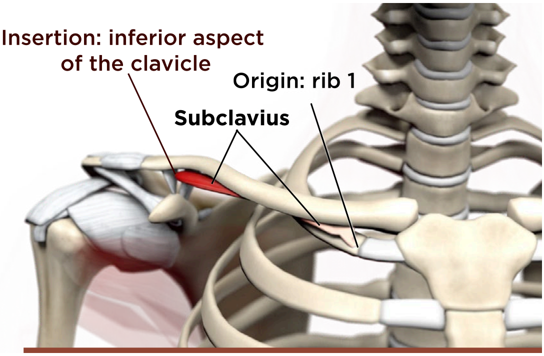
Rhomboid minor typically takes origin from the spinous processes of C7 and T1, and inferior to that, rhomboid major originates usually from the spinous processes of the second through fifth thoracic vertebrae. Both muscles insert on the medial or vertebral border of the scapula; rhomboid minor inserts near the base of the scapular spine, and rhomboid major inserts inferior to the spine of the scapula. Both muscles can act to elevate the scapula as well as retract or adduct it, fixing it to the thorax. And like levator scapulae, their oblique angle helps them rotate the scapula to point the glenoid cavity inferiorly.



Serratus anterior has an interesting origin, like a series of fingers of muscle taking origin off the anterolateral ribs. It sneaks around, deep to the scapula, and attaches to its medial or vertebral border—but on the anterior side of the bone, meaning the side of the scapula that faces the ribs. Serratus anterior can protract the scapula, bringing it forward, but it also helps fix the scapula against the rib cage, holding it so that other muscles that originate on the scapula can do their jobs. Serratus anterior also allows abduction of the upper limb above the horizontal plane. Without serratus anterior to rotate the scapula so that the glenoid fossa faces upward, we wouldn't be able to clear the shelf of the bone at the AC joint for full range of abduction at the shoulder. Also, serratus anterior is the only muscle supplied by the long thoracic nerve off the roots of the brachial plexus, and—unlike nearly all other muscles that are innervated on their deep side—the long thoracic nerve enters serratus anterior's superficial side.



Another muscle that takes origin off the ribs and attaches to the scapula is pectoralis minor. It originates off of typically three of the upper ribs, ribs two to four or three to five. It helps stabilize the scapula in place but can also help depress it. And when the scapula is fixed—in other words, held in place by other muscles—pectoralis minor can assist in raising the ribs. The medial pectoral nerve off the medial cord of the brachial plexus supplies pectoralis minor.

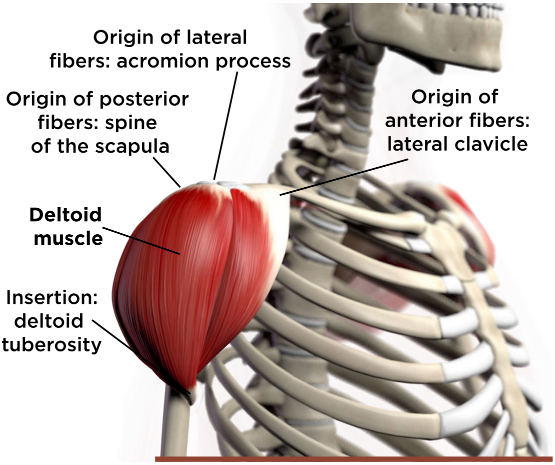


Last in the group of muscles that originate on the axial skeleton and insert on the pectoral girdle is subclavius. It originates on the first rib and inserts on the inferior aspect of the clavicle. This helps stabilize the clavicle during movements of the shoulder girdle and can also slightly depress the clavicle. It is supplied by the so-called nerve to the subclavius off the upper trunk of the brachial plexus.

Two muscles of the shoulder area originate all or in part from the axial skeleton and attach to the humerus: pectoralis major and latissimus dorsi. Pectoralis major has a clavicular head that originates from the medial half of the clavicle, and its sternal head takes origin from the sternum and upper six costal cartilages. Latissimus dorsi originates from the spinous processes of the lower six thoracic vertebrae and five lumbar vertebrae, as well as the pelvis, lower ribs, and thoracolumbar fascia.

Because of their insertions, these two muscles share two of their three functions. Pectoralis major and latissimus dorsi both insert on the intertubercular/bicipital groove on the humerus. Because they both cross the axilla, they adduct the humerus, and since they both attach anteriorly to the proximal humerus, they both medially rotate the humerus. But because it is on the anterior side of the body, pectoralis major can aid in flexion of the shoulder, while latissimus dorsi, located posteriorly, extends the humerus. Latissimus dorsi is supplied by the thoracodorsal nerve off the posterior cord, while pectoralis major is supplied by both the medial and lateral pectoral nerves.

Next, there is a group of nine muscles that connect the shoulder girdle to the humerus or the radius or ulna. First, biceps brachii and triceps brachii are each a multiheaded muscle that has one or two heads that cross the shoulder joint, but their main actions are at the elbow. That leaves three non-rotator-cuff muscles—deltoid, coracobrachialis, and teres major—plus the four muscles of the rotator cuff as the remaining muscles that act at the shoulder.


Origin of lateral fibers: acromion process
Origin of posterior fibers: spine of the scapula
Origin of anterior fibers: lateral clavicle
Deltoid muscle
Insertion: deltoid tuberosity

The deltoid muscle makes up the rounded prominence at the shoulder. It has the same origin as the trapezius: along the lateral clavicle, the acromion process, and spine of the scapula. It inserts on the deltoid tuberosity of the humerus and is one of two muscles supplied by the axillary nerve, one of the five terminal branches of the brachial plexus. The anterior fibers of the deltoid aid flexion and medial rotation of the shoulder, and the posterior fibers aid extension and lateral rotation of the shoulder, but the lateral fibers abduct the humerus to horizontal. Beyond that, serratus anterior has to rotate the scapula to reach any higher.

Coracobrachialis is a small muscle that originates on the coracoid process of the scapula and inserts on the proximal humerus. Coracobrachialis is a weak muscle that contributes to shoulder adduction. Like the other muscles of the anterior arm, coracobrachialis is supplied by the musculocutaneous nerve—another of the five terminal branches of the brachial plexus.

Teres major originates on the inferior aspect of the axillary or lateral border of the posterior scapula and inserts on the intertubercular groove of the humerus. Teres major has the same functions as latissimus dorsi—it extends, adducts, and medially rotates the arm— but it is supplied by the lower subscapular nerve off the posterior cord of the brachial plexus.

Last is the group of shoulder muscles known as the rotator cuff. This is a series of four muscles—supraspinatus, infraspinatus, teres minor, and subscapularis—that all connect the scapula to the humerus, forming a cuff of muscles around the head of the humerus.

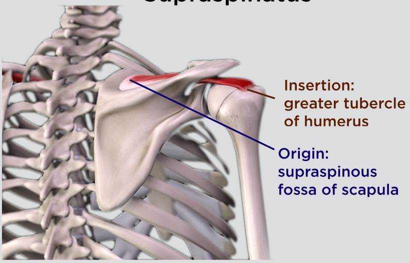
Despite the name *rotator cuff*, not all of the muscles in this group rotate.

Supraspinatus conveniently originates in the supraspinous fossa and inserts on the greater tubercle of the humerus, but it abducts, as its superior position at the shoulder suggests. In fact, it performs about the first 10% of abduction and then the lateral fibers of deltoid kick in to take the humerus to horizontal, followed by serratus anterior rotating the scapula.

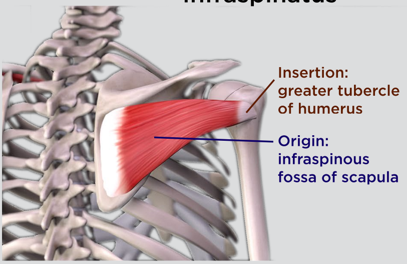
Infraspinatus originates in the infraspinous fossa, also convenient, and like supraspinatus attaches to the greater tubercle—but posteriorly, so it laterally rotates the arm. Both the supraspinatus and infraspinatus are supplied by the suprascapular nerve off the upper trunk of the brachial plexus.

Teres minor originates on the scapula just lateral to the infraspinatus and inserts just inferior to it on the posterior humerus, so it laterally rotates the shoulder. It is the only other muscle, besides the deltoid, that's supplied by the axillary nerve of the brachial plexus.

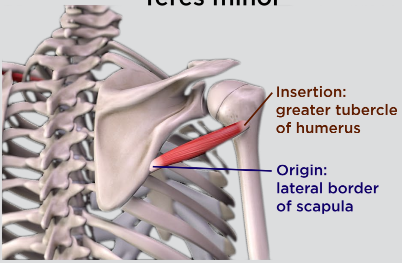
Supraspinatus


Insertion:
greater tubercle
of humerus
Origin:
supraspinous
fossa of scapula

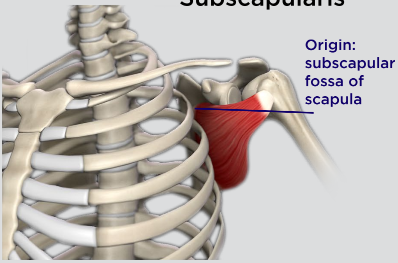
Infraspinatus


Insertion:
greater tubercle
of humerus
Origin:
infraspinous
fossa of scapula

Teres minor


Insertion:
greater tubercle
of humerus
Origin:
lateral border
of scapula

Subscapularis


Origin:
subscapular
fossa of
scapula

Finally, subscapularis, as its name suggests, originates on the subscapular fossa, which is on the anterior surface of the scapula, and inserts on the lesser tubercle on the anterior humerus. For this reason, it medially rotates the arm at the shoulder. Both the upper and lower subscapular nerves off the posterior cord supply subscapularis.

Beyond any rotation, the rotator cuff muscles share the important function of stabilizing the capsule of the shoulder joint from nearly all directions: supraspinatus superiorly, infraspinatus and teres minor posteriorly, and subscapularis anteriorly. Sometimes the mnemonic "SITS" is used for the four muscles that sit around the shoulder joint and stabilize the head of the humerus in the glenoid fossa.

Reading

Biel, *Trail Guide to the Body*, ch. 2, "Shoulder & Arm."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 7, "Muscles of the Shoulder and Upper Arm."

Delavier, *Strength Training Anatomy*, ch. 2, "Shoulder."

Dimon, *Anatomy in Action*, ch. 9, "The Shoulder Girdle."

Jarmey, *The Concise Book of Muscles*, ch. 7, "Muscles of the Shoulder and Arm."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 6, "Muscles of the Shoulder and Arm."

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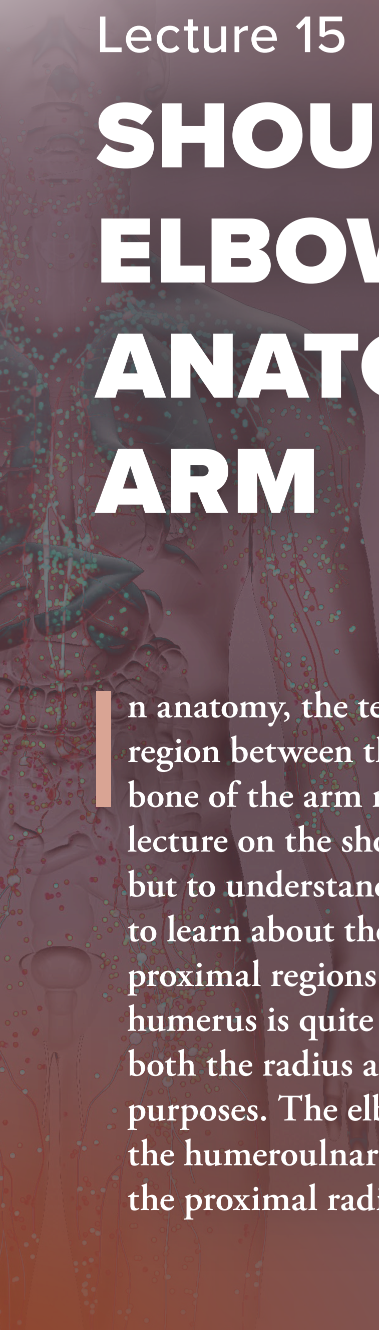
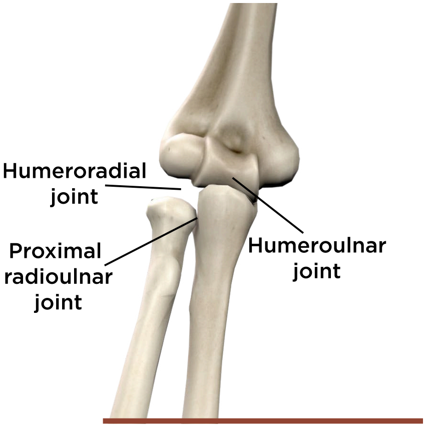


Lecture 15

SHOULDER TO ELBOW: THE ANATOMICAL ARM

In anatomy, the term *arm* refers specifically to the region between the shoulder and the elbow. The bone of the arm region is the humerus. The previous lecture on the shoulder covered its proximal end, but to understand the elbow articulation, you need to learn about the distal humerus, as well as the proximal regions of the radius and ulna. The distal humerus is quite complex, because it articulates with both the radius and the ulna, and for two different purposes. The elbow is really a group of three joints: the humeroulnar joint, the humeroradial joint, and the proximal radioulnar joint.

The Humerus, the Radius, and the Ulna



The previous lecture left off its review of the landmarks on the humerus with the deltoid tuberosity, which is where the deltoid muscle inserts. At about the same vertical level but on the posterior aspect of the humerus is the radial or spiral groove*—approximately at mid-shaft, where the radial nerve and its accompanying profunda brachii artery (also known as the deep brachial artery) run along the humerus together.

Proceeding distally, the humerus has a pair of epicondyles, medial and lateral. The medial is larger and more easily felt at the elbow. The medial epicondyle is a common origin for several flexor muscles of the anterior forearm. The lateral epicondyle is a common site of origin for many extensor muscles of the posterior forearm. *Epi-* means "above," so you'd think the area distal to these epicondyles would be called the medial and lateral condyles, but that's not so in the humerus. This is because it articulates with both the radius and ulna—for essentially different functions.

The entire shoulder-to-fingers structure can be called the upper limb, upper extremity, or upper appendage, depending on clinical specialty. Anatomists tend to use the word *limb*.

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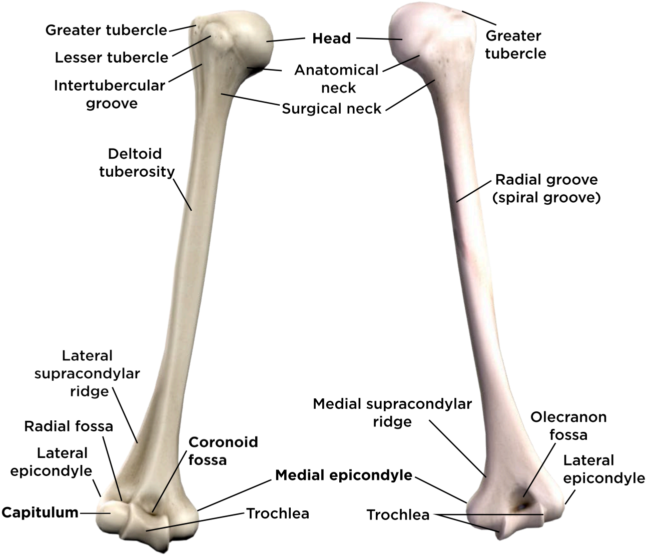
* Because the groove spirals around the posterior humerus, some sources call it the spiral groove, but the placement of the radial nerve—one of the terminal branches of the brachial plexus—gives it the alternate name *radial groove*.


Greater tubercle
Lesser tubercle
Intertubercular groove
Deltoid tuberosity
Head
Anatomical neck
Surgical neck
Greater tubercle
Radial groove (spiral groove)
Lateral supracondylar ridge
Radial fossa
Lateral epicondyle
Capitulum
Coronoid fossa
Medial epicondyle
Trochlea
Medial supracondylar ridge
Olecranon fossa
Lateral epicondyle
Trochlea

The medial aspect of the articular region is called the *trochlea*, which is Latin for "pulley," since it resembles a spool. The proximal ulna has a corresponding trochlear notch that forms a hinge joint with the trochlea of the humerus.

The lateral part of the articular surface of the distal humerus is called the capitulum; it's like a rounded knob, and it articulates with the head of the radius. *Capit-* means "head," so the drum-shaped radial head, which is proximal, forms a joint with the capitulum of the distal humerus. This forms the pivot or rotational joint at which pronation and supination occur. And though that motion is most obvious at the wrist or hand, it also happens at the elbow.

The trochlear notch on the ulna is *U*-shaped to help form the hinge joint between the humerus and ulna. The proximal and more posterior end of the trochlear notch is a large prominence known as the olecranon process of the ulna. It's the large bump you can easily feel on the posterior elbow. The more anterior end of the trochlear notch is a smaller coronoid† process.

To complete the posterior part of the hinge joint, the distal humerus has an olecranon fossa, which serves as a deep spot for the olecranon process of the ulna to sit in when the elbow is fully extended. Anteriorly, the distal humerus has a coronoid fossa medially and a radial fossa laterally to accommodate the coronoid process of the ulna and the radial head when the elbow is maximally flexed.

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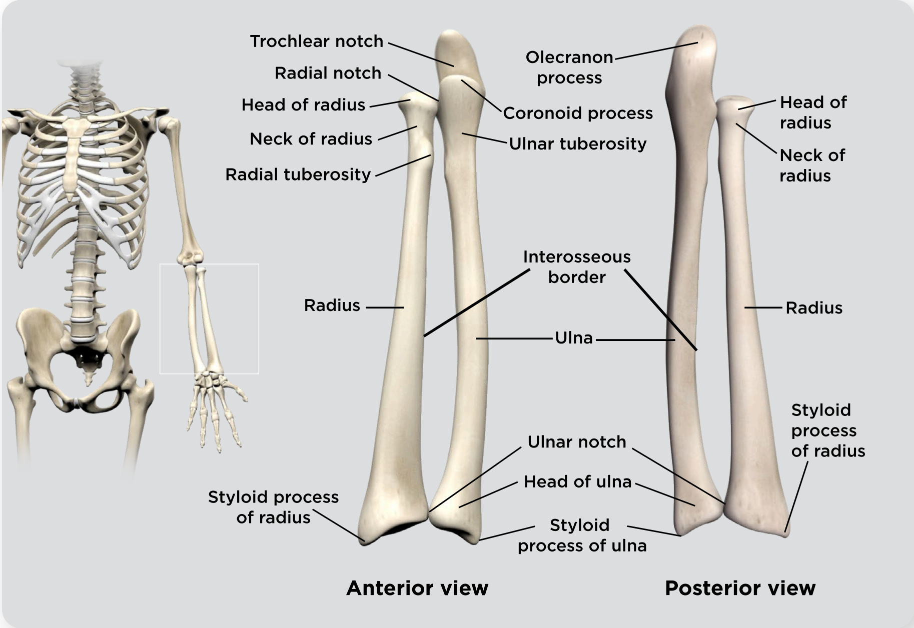
† This is perhaps so named because it sticks up like the point on a crown.


Trochlear notch
Radial notch
Head of radius
Neck of radius
Radial tuberosity
Olecranon process
Coronoid process
Ulnar tuberosity
Head of radius
Neck of radius
Interosseous border
Radius
Ulna
Radius
Ulnar notch
Head of ulna
Styloid process of radius
Styloid process of ulna
Styloid process of radius
Anterior view
Posterior view

The other landmark on the proximal ulna that is relevant to the elbow joint is the radial notch, which helps form the radioulnar joint by receiving the head of the radius as it rotates during pronation and supination.

Distal to its head, the radius has a constricted region called the neck. The radial tuberosity is a prominence on the anterior aspect of the proximal shaft of the radius, while the ulnar tuberosity is a prominence on the anterior aspect of the proximal shaft of the ulna.

A fossa or a notch is often named for the bone or landmark it is receiving, rather than the bone it is on.

Along their shafts, both the radius and ulna have a sharp interosseous border or crest, each of which faces the other and serves as an attachment for the interosseous membrane. The interosseous membrane supports the linkage between the radius and ulna and divides the muscles of the forearm into anterior and posterior compartments.

The ulna has a head, but it is distally placed; in fact, it's the bump you can see and feel on the back of your wrist on the little finger side. The distal radius has a counterpart ulnar notch to receive the head of the ulna, but there's no rotation at the wrist like there is at the elbow during the movements of pronation and supination.

At the wrist, both the radius and ulna have tip-like extensions of their distal ends called styloid processes. The styloid process of the radius is a lateral projection off its distal end, and the styloid process of the ulna is a medial projection off its distal end.

The Elbow's Ligaments and the Movements They Allow

Since the articulation between the humerus and ulna forms a hinge joint, the elbow—like other hinge joints—has a pair of collateral‡ ligaments. The ulnar collateral ligament joins the medial epicondyle of the humerus to the olecranon and coronoid processes of the ulna. It stabilizes the medial side of the elbow joint.

The radial collateral ligament attaches to the lateral epicondyle of the humerus; however, it doesn't attach to the radius. This is because the head of the radius has to spin around on the capitulum of the humerus during pronation and supination. If the radial collateral ligament attached to the radius, it would interfere with its rotational movement.

So, the head of the radius is surrounded by another ligament called the annular ligament. This ligament not only holds the head of the radius in place but also serves as the distal attachment of the radial collateral ligament, stabilizing the lateral aspect of the hinge joint at the elbow while still allowing the rotation of the radius during pronation and supination.

The Arm's Muscular Compartments

The elbow is clearly a complicated combination of joints—but in terms of muscles, the arm is by far the simplest region in the upper limb. The arm has two muscular compartments: an anterior and a posterior.

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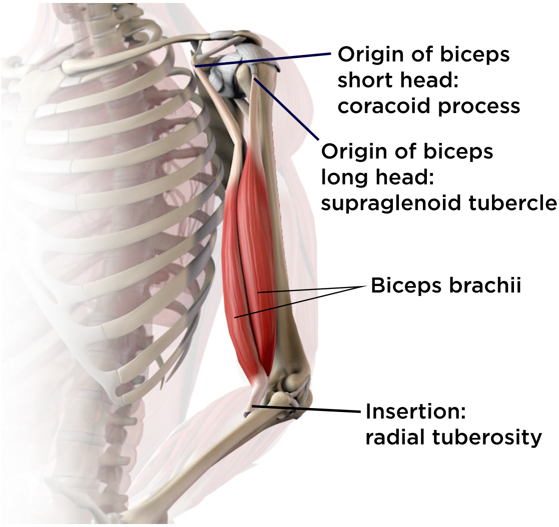
‡ *Collateral* here means "both sides" or "mutual sides."

The anterior arm contains three muscles, all of which are supplied by the musculocutaneous nerve—one of the terminal branches of the brachial plexus, off its lateral cord. You've already encountered two of these muscles since they cross the shoulder.

Coracobrachialis—which originates on the coracoid process of the scapula and inserts on the proximal humerus—only crosses the shoulder. It is a puny muscle that weakly adducts and, some sources say, weakly flexes the shoulder. The musculocutaneous nerve typically enters the anterior arm by directly piercing the coracobrachialis muscle and passing through it as it innervates the compartment.

Also previously mentioned is biceps brachii, which crosses both the shoulder and the elbow. As its name implies, the biceps brachii has two heads. The so-called short head originates on the coracoid process of the scapula alongside coracobrachialis. But the long head of the biceps brachii takes origin off the supraglenoid tubercle—the small bump superior to the glenoid fossa.

This long tendon of the biceps brachii passes into the capsule of the shoulder joint, which is unusual for a tendon, and enters the intertubercular groove between the greater and lesser tubercles on the proximal humerus.§ A small ligament called the transverse humeral ligament—part of the capsule of the shoulder joint—holds the tendon of the long head of the biceps brachii in place in the intertubercular groove. Due to crossing the shoulder, biceps brachii is said to perform weak flexion there.


Origin of biceps short head: coracoid process
Origin of biceps long head: supraglenoid tubercle
Biceps brachii
Insertion: radial tuberosity

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§ This is also called the bicipital groove for the biceps brachii tendon it holds.

The long and short heads converge, and the insertion of the biceps brachii muscle is on the radial tuberosity. But part of the insertion, known as the bicipital aponeurosis, stays superficial; it reaches across the cubital fossa anterior to the elbow and inserts on the antebrachial fascia—the sleeve around the muscles of the forearm.

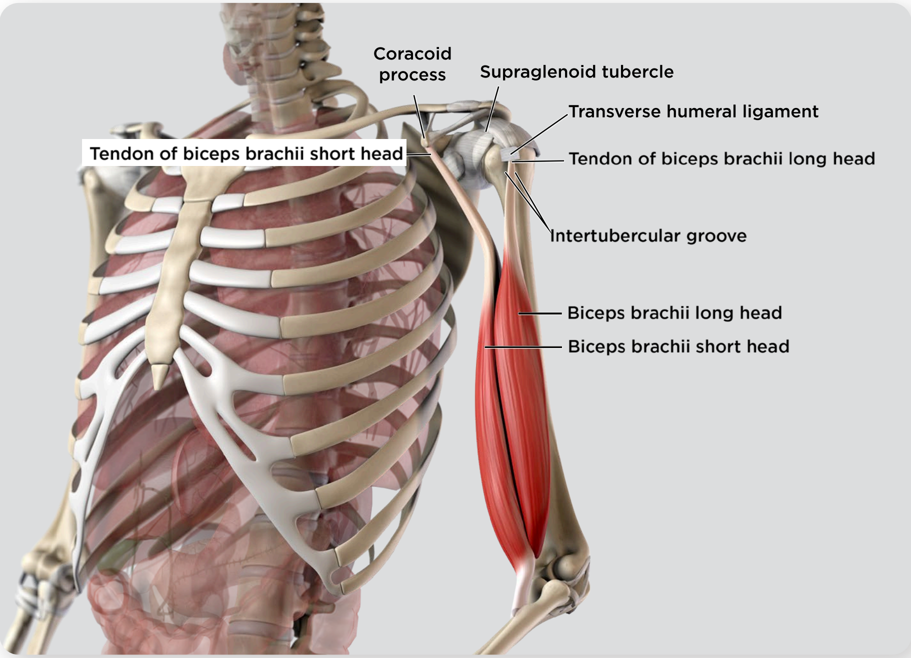
The bicipital aponeurosis helps protect some of the important contents of the cubital fossa, such as the brachial artery and the median nerve, which pass deep to the bicipital aponeurosis. If you bend your elbow, allowing your arm to hold the weight of your forearm and hand, you can feel the biceps brachii tendon superficially at the front of your bent elbow.

The biceps brachii is the main flexor of the elbow. Due to the attachment on the radial tuberosity, the biceps brachii doesn't only flex the elbow but also helps supinate the forearm at the elbow. Consider that for any muscle to supinate or pronate, it must attach to the radius—not the ulna. Remember, the joint between the trochlear notch of the ulna and the trochlea of the humerus is a hinge joint, so the ulna cannot possibly pronate or supinate. You can easily demonstrate that to yourself, since you can feel your ulna down the length of your forearm, and when you pronate and supinate, you can feel that it does not move. The biceps brachii's insertion on the radial tuberosity helps pull the pronated radius into a supinated position.

The third and final muscle of the anterior compartment of the arm is the brachialis, which only crosses the elbow. It takes origin off the distal half of the anterior humerus and inserts on the ulnar tuberosity and coracoid process of the proximal ulna. The brachialis should get the top billing as the main flexor of the elbow—and that's its only function. Brachialis is the one muscle of the anterior arm that doesn't cross the shoulder.

Many references say only one muscle—the triceps brachii—lives in the posterior compartment of the arm, but there is also a another seldom-discussed muscle, anconeus.

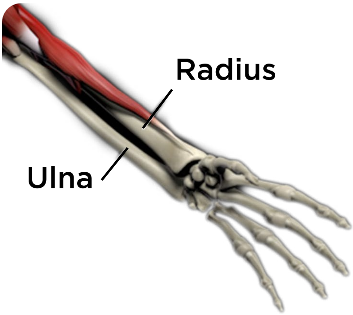
> The coracobrachialis crosses only the shoulder, the brachialis crosses only the elbow, and the biceps brachii crosses both.


Coracoid process
Supraglenoid tubercle
Transverse humeral ligament
Tendon of biceps brachii short head
Tendon of biceps brachii long head
Intertubercular groove
Biceps brachii long head
Biceps brachii short head

Triceps brachii has three heads. Its long head originates on the infraglenoid tubercle of the scapula; its other two heads are lateral and medial. The long head is the only of the three that crosses the shoulder, and there it helps stabilize and weakly extends the shoulder. The triceps brachii's lateral head originates on the proximal aspect of the posterior humerus, and the medial head originates on the more distal aspect of the posterior humerus. The radial nerve descends the posterior arm by passing in the spiral or radial groove that runs between the origins of the lateral and medial heads. All three heads converge as a single muscle belly that inserts on the olecranon process of the ulna.

Since the triceps brachii crosses the posterior aspect of the elbow, its function is extension of the elbow. And remember that all muscles of the posterior arm and forearm are supplied by the radial nerve off the posterior cord of the brachial plexus.

Anconeus is a small muscle that's also supplied by the radial nerve, and anconeus also extends the elbow. It originates off the posterior side of the medial epicondyle of the humerus and inserts on the lateral aspect of the olecranon process of the ulna and the proximal region of the ulna's posterior shaft. Anconeus assists triceps brachii in its function, but its small belly is technically distal to the elbow joint.



Reading

Biel, *Trail Guide to the Body*, ch. 2, "Shoulder & Arm."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 7, "Muscles of the Shoulder and Upper Arm."

Delavier, *Strength Training Anatomy*, ch. 1, "Arms."

Dimon, *Anatomy in Action*, ch. 10, "The Arms."

Jarmey, *The Concise Book of Muscles*, ch. 7, "Muscles of the Shoulder and Arm."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 6, "Muscles of the Shoulder and Arm."

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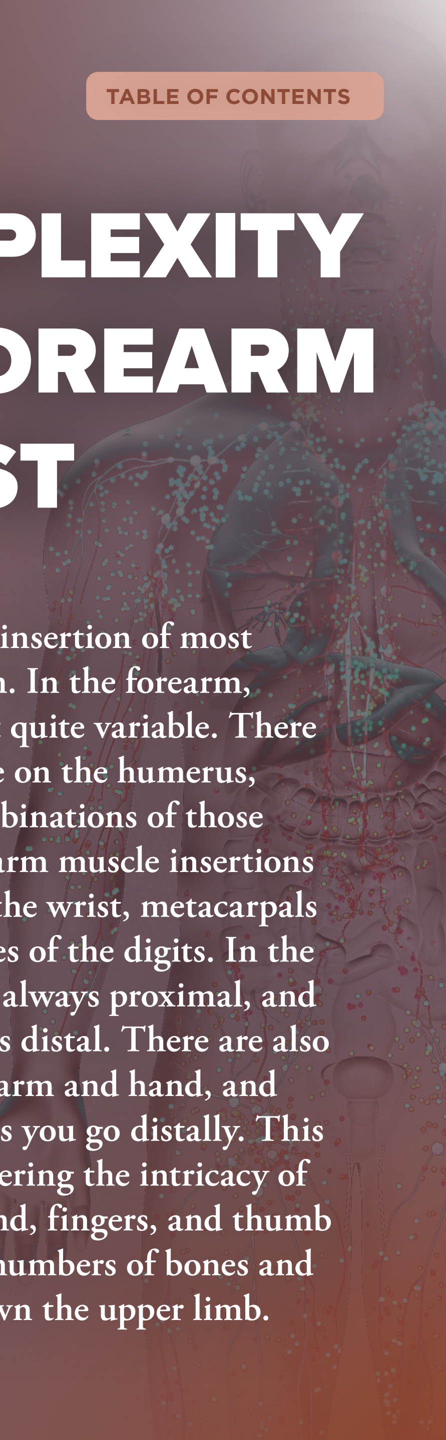
Lecture 16

THE COMPLEXITY OF THE FOREARM AND WRIST



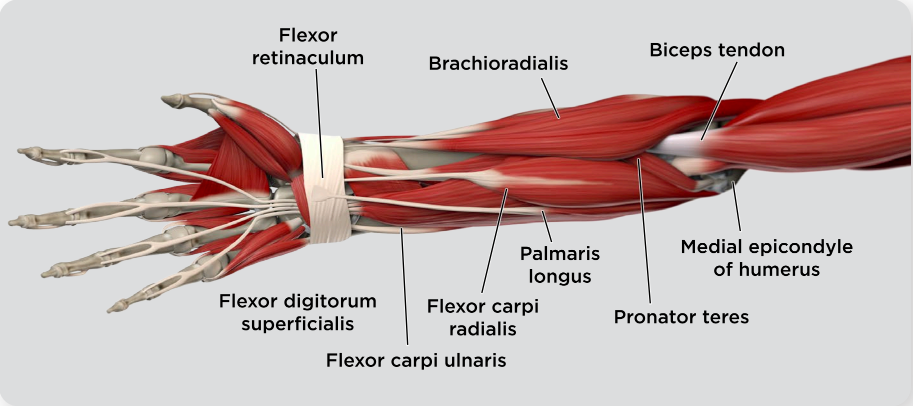
The forearm bones are the insertion of most muscles in the arm region. In the forearm, origins and insertions get quite variable. There are muscles that originate on the humerus, radius, or ulna or on combinations of those bones, and there are forearm muscle insertions on the radius, carpals of the wrist, metacarpals of the hand, and the bones of the digits. In the limbs, muscle origins are always proximal, and their insertions are always distal. There are also many muscles in the forearm and hand, and they tend to get smaller as you go distally. This makes sense when considering the intricacy of the movements of the hand, fingers, and thumb as well as the increasing numbers of bones and joints as you progress down the upper limb.

The Anterior Forearm

The radius is lateral and the ulna is medial, and the two bones in the forearm are joined by the interosseous membrane. That deep plane of fascia combines with the sleeve of antebrachial fascia and its attachment to the bones of the forearm to create two compartments in the forearm: an anterior and a posterior.

Many muscles in the anterior forearm cross the anterior wrist and flex the wrist; several of these muscles also reach the digits and flex them, too. But in the anterior compartment of the forearm, there is a pair of muscles that pronate the wrist and hand, which happens at the elbow. In the posterior forearm are counterpart muscles that extend the wrist and digits and a supinator of the forearm at the elbow. Also in the posterior forearm is a group of muscles that act specifically on the thumb. But at the lateral edges in both the anterior and posterior forearm are muscles that abduct the wrist and hand—an action also called radial deviation. And at the medial edges in both compartments are muscles that adduct the wrist and hand, also known as ulnar deviation.

Since muscles in the proximal forearm may pass their tendons all the way to the wrist and digits, there are thickenings in the antebrachial fascia at the wrist known as retinacula. There's a flexor retinaculum at the anterior wrist that is continuous with the extensor retinaculum at the posterior wrist. These act like a band or binding and function to keep the tendons aligned with the joints they act on. Anteriorly at the wrist, part of this flexor retinaculum forms the compartment for tendons known as the carpal tunnel.

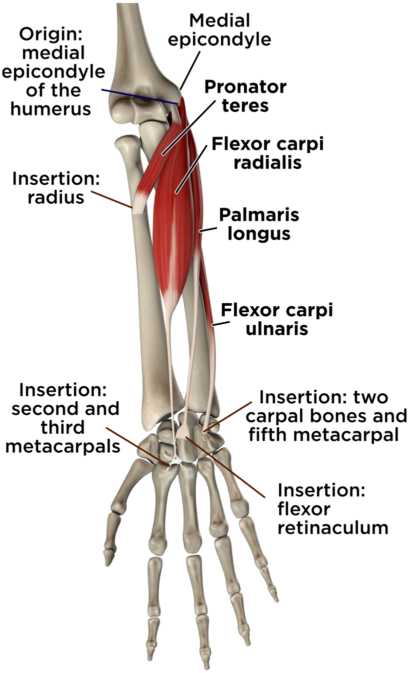

Flexor retinaculum
Brachioradialis
Biceps tendon
Palmaris longus
Medial epicondyle of humerus
Flexor digitorum superficialis
Flexor carpi radialis
Pronator teres
Flexor carpi ulnaris

The anterior compartment has either seven or eight muscles in it, depending on human variability. A few muscles in the body are quite commonly variable, and palmaris longus is one of those. The eight possible muscles are subdivided into a superficial layer and a deep layer, and the variable palmaris longus muscle is superficial.

There are either four or five muscles in the superficial group and three muscles in the deep group. What links the superficial muscles together is that all have at least part of their origin off the medial epicondyle of the humerus—an area known as the common flexor origin, since nearly all of these muscles flex the wrist or digits. It should also be noted that when you look at the anterior forearm, you can readily see some muscles of the posterior forearm at the lateral edge. That wad of muscle seen at the lateral elbow consists of three muscles of the posterior forearm that wrap around to the anterior side.

Starting at the medial border of the triangular cubital fossa, the muscles of the superficial group in the anterior forearm start with the pronator teres,* the smallest of the group. It originates off the medial epicondyle of the humerus. And, in order to pronate or supinate, it inserts on the radius about midway down its shaft. Since pronator teres crosses the anterior elbow, it also aids in flexion of the elbow.

Next in line off the common flexor origin is the *flexor carpi*† *radialis*, which means "a flexor of the wrist on the radial, or lateral, side." It takes origin off the medial epicondyle, passes obliquely down the forearm toward the wrist, and inserts on the second and third metacarpals in the palmar hand. Given its lateral insertion, it also causes abduction of the wrist, alternatively called radial deviation.


Origin: medial epicondyle of the humerus
Medial epicondyle
Pronator teres
Flexor carpi radialis
Insertion: radius
Palmaris longus
Flexor carpi ulnaris
Insertion: second and third metacarpals
Insertion: two carpal bones and fifth metacarpal
Insertion: flexor retinaculum

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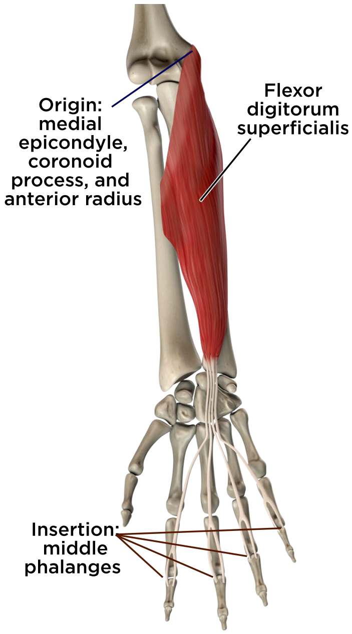
* *Teres* means "round," since the muscle is round in cross section.

† Despite having *carpi* in its name, it doesn't insert on the carpal bones of the wrist themselves.


Origin: medial epicondyle, coronoid process, and anterior radius
Flexor digitorum superficialis
Insertion: middle phalanges

Flexor digitorum superficialis, as its name implies, is a superficially placed flexor of the digits—specifically the four fingers. It has a broad origin, with part coming off the medial epicondyle, part off the coronoid process on the ulna, and part off the anterior radius. Its muscle belly sends four tendons through the carpal tunnel and on to insert on the middle phalanges of the four fingers. Each finger contains three phalanges: a proximal, middle, and distal.

Then, on the medial side in this superficial layer is the flexor carpi ulnaris, which takes origin off the medial epicondyle and then inserts on two of the carpal bones of the wrist and the fifth metacarpal of the palm. Flexor carpi ulnaris is so medially located that it doesn't only flex the wrist but also performs wrist adduction, called ulnar deviation.

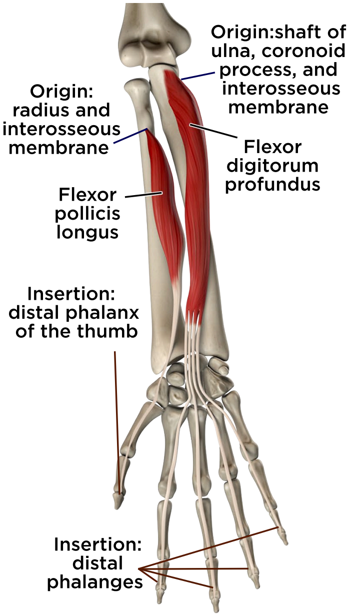
Those are the four standard muscles of the superficial group of the anterior forearm. Like the other muscles of the superficial group, the variable muscle palmaris longus originates off of the medial epicondyle. When present, it has a small and proximal muscle belly and a long tendon that inserts on the flexor retinaculum that forms the carpal tunnel, and it additionally inserts on a fascial structure of the hand called the palmar aponeurosis.

Palmaris longus is the most variable muscle in the world. Its presence ranges widely, from about 36% to nearly 99%, depending on the research study.

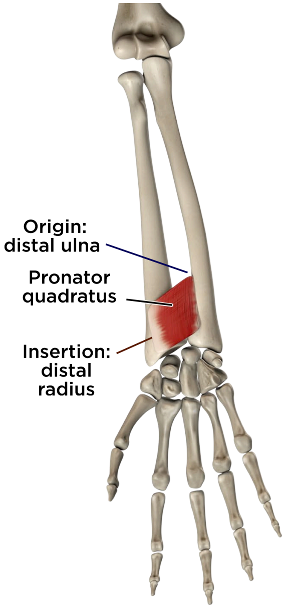
None of the three muscles in the deep group of the anterior forearm originate off the common flexor origin of the medial epicondyle. The largest by far is the flexor digitorum profundus, which takes origin off the shaft of the ulna and its coronoid process as well as off the interosseous membrane—since it is deep, as the name *profundus* implies.

Like its superficialis buddy, flexor digitorum profundus crosses the wrist within the carpal tunnel, and its four tendons insert on the distal phalanges of the fingers. Because flexor digitorum superficialis and profundus both cross the anterior wrist, they also help flex the wrist.

The second muscle of the deep anterior forearm is the flexor pollicis longus. And given that *pollex* means "thumb," this is a flexor of the thumb that originates on the radius and interosseous membrane and inserts on the distal phalanx of the thumb—which only has two phalanges, not three as in the fingers.


Origin:shaft of ulna, coronoid process, and interosseous membrane
Origin: radius and interosseous membrane
Flexor digitorum profundus
Flexor pollicis longus
Insertion: distal phalanx of the thumb
Insertion: distal phalanges

Flexor pollicis longus also passes through the carpal tunnel made by the flexor retinaculum of the wrist. So, the carpal tunnel contains nine tendons belonging to three muscles: one tendon from flexor pollicis longus, four tendons from flexor digitorum superficialis, and four tendons from flexor digitorum profundus. The carpal tunnel also contains the median nerve.


Origin: distal ulna
Pronator quadratus
Insertion: distal radius

The last of the deep muscles in the anterior compartment of the forearm is pronator quadratus, the companion muscle to pronator teres. Pronator quadratus is flat and quadrangular in shape and runs perpendicular to the two bones of the forearm. Pronator quadratus originates on the distal ulna and inserts on the radius in order to pronate.

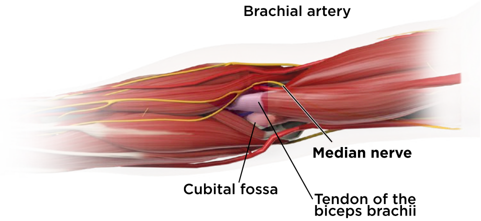
So, those are the seven standard muscles and one variable muscle of the anterior forearm, most of which act to flex the wrist or digits.

The median and ulnar nerves are terminal branches that pass through the anterior arm to reach and supply muscles of the anterior forearm and in the palmar hand.

The median nerve passes through the center of the cubital fossa‡ to reach the anterior forearm. The ulnar nerve passes through the medial arm and then ducks behind the medial epicondyle on its way to the anterior forearm. And at the elbow, the ulnar nerve sits between the medial epicondyle and the olecranon process.

The medial epicondyle is what causes the pins and needles feeling when you accidentally bang your so-called funny bone.

Once the pair of nerves reach the anterior forearm, most muscles are supplied by the median nerve; only one and a half anterior compartment muscles are supplied by the ulnar nerve. In the superficial group, the median nerve supplies all muscles except the one with *ulnar* in its name: flexor carpi ulnaris. So, the median nerve supplies pronator teres, flexor carpi radialis, flexor digitorum superficialis, and palmaris longus.



In the deep group, two and a half muscles are supplied by the median nerve—specifically, the anterior interosseous branch of the median nerve, which comes off the median nerve and dives deep in the anterior compartment to descend along the interosseous membrane, thus its name. The flexor pollicis longus and pronator quadratus are both supplied by the anterior interosseous nerve, but the flexor digitorum profundus has dual innervation from both the anterior interosseous branch of the median nerve and the ulnar nerve. The medial half of flexor digitorum profundus is supplied by the ulnar nerve, and the lateral half is supplied by the median nerve's anterior interosseous branch.

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‡ The mnemonic *TAN* is used for the relationships of the central structures at the cubital fossa: The *T* is for the *tendon* of the biceps brachii, the *A* is for the brachial *artery* just medial to it, and more medial still, the *N* stands for the median *nerve*.

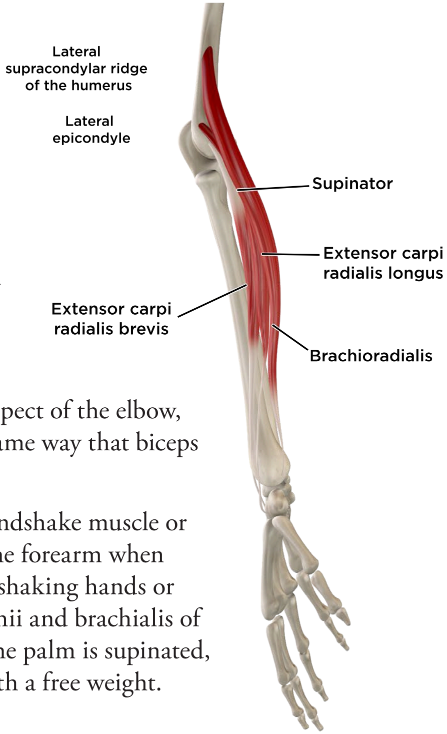
The Posterior Forearm

The posterior forearm has even more muscles than the anterior compartment—11 muscles total, which are typically divided into two main groups: a superficial set of six muscles and five deeper muscles.

The superficial muscles all take origin on or just proximal to the lateral epicondyle, which is called the common extensor origin. The six superficial muscles are sometimes subdivided into two groups: a superficial lateral group of three—the ones that can be seen even from the anterior side, at the lateral-most aspect of the forearm near the elbow—and a superficial posterior group of three that cannot be seen anteriorly. All of these are supplied by the radial nerve or one of its branches, and most extend the wrist or digits or act on the thumb.

The superficial lateral group seen just lateral to the elbow are the brachioradialis, the extensor carpi radialis longus, and extensor carpi radialis brevis.

Brachioradialis doesn't cross the wrist. Its name tells us that it starts on the bone of the brachium, which is the humerus, and it inserts on the radius—specifically the distal radius, including its styloid process. Brachioradialis is very unusual for a posterior forearm muscle because it crosses the anterior aspect of the elbow, so it flexes the elbow—but not in the same way that biceps brachii and brachialis act.

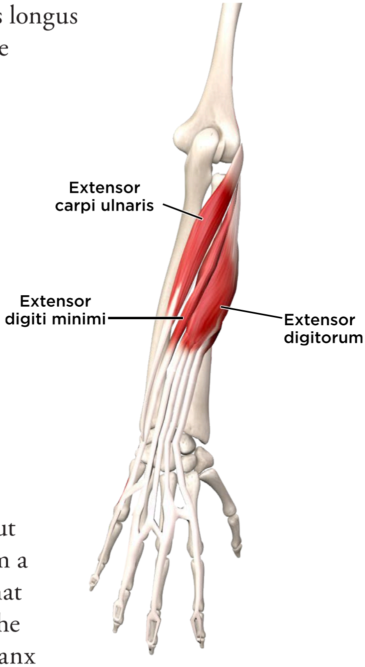

Lateral supracondylar ridge of the humerus
Lateral epicondyle
Supinator
Extensor carpi radialis longus
Extensor carpi radialis brevis
Brachioradialis

Brachioradialis is also known as the handshake muscle or the drinking muscle because it flexes the forearm when the palm faces medially, as if you were shaking hands or drinking from a cup, while biceps brachii and brachialis of the anterior arm flex the elbow when the palm is supinated, or facing up, as if doing biceps curls with a free weight.

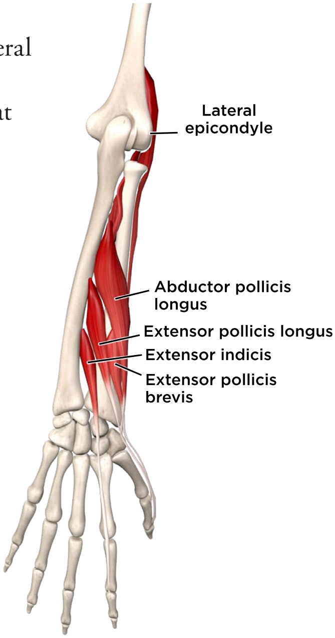
The other two members of this so-called superficial lateral group, extensor carpi radialis longus and extensor carpi radialis brevis, are the only carpi muscles that have longus and brevis counterparts. Not only do they extend the wrist, as their name implies, but they also cause radial deviation, or abduction at the wrist. The extensor carpi radialis longus is more superficial and inserts on the proximal base of the second metacarpal, while the extensor carpi radialis brevis is deep to its longus buddy and inserts on the proximal base of the third metacarpal.

The other three superficial muscles are more posteriorly located and so are sometimes called the superficial posterior three. They are the extensor digitorum, extensor digiti minimi, and extensor carpi ulnaris.

Unlike the anterior compartment, where there's a pair of flexors of the digits—superficialis and profundus—the posterior compartment simply has extensor digitorum. It sends a tendon down to extend all four fingers; often its tendons have connections between them on the dorsum of the hand. But the little finger has an additional tendon from a small muscle called extensor digiti minimi that passes from the common extensor origin of the lateral epicondyle down to the proximal phalanx of the pinkie finger to extend it. Extensor carpi ulnaris is at the medial edge of the posterior forearm and inserts on the proximal base of the fifth metacarpal—the bone of the palm on the little finger side. In addition to extending the wrist, extensor carpi ulnaris causes wrist adduction or ulnar deviation.



The group of five deep muscles of the posterior forearm that do not take origin off the lateral epicondyle includes three muscles called the snuffbox muscles.



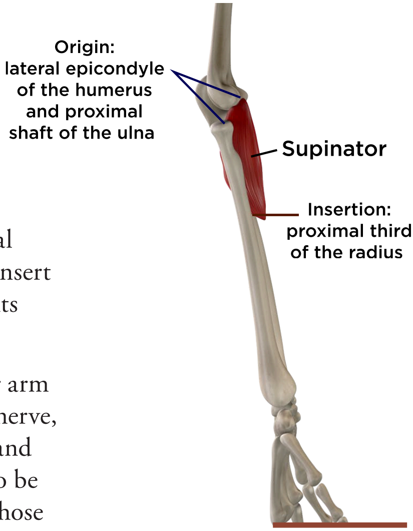
The surface landmark known as the anatomical snuffbox is a triangular region on the posterolateral aspect of the thumb where three muscles of the posterior forearm travel to reach the thumb. That area gets its strange name because in the old days, people who did snuff would put a pinch of the dry, powdery tobacco mix on the flat spot at the back of the thumb and then snort it into a nostril. The snuffbox muscles are also known as the outcropper muscles because they "crop out" between the superficial lateral and superficial posterior muscles and so are helpful in differentiating those two superficial groups.

The three outcropper muscles are the extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus. The triangle of the anatomical snuffbox is caused by the fact that the extensor pollicis longus travels by itself on the more medial aspect of the posterior thumb, while the extensor pollicis brevis and abductor pollicis longus travel together on the lateral-most aspect of the posterior thumb.

Extensor pollicis longus originates from the mid-shaft of the posterior ulna and the interosseous membrane and inserts on the base of the distal phalanx of the thumb. The extensor pollicis brevis originates from the mid-shaft of the posterior radius and the interosseous membrane and inserts on the base of the proximal phalanx of the thumb.

Abductor pollicis longus originates on both the radius and ulna, as well as the interosseous membrane, and inserts on the posterior surface of the base of the first metacarpal.

One of the remaining two deep muscles of the posterior forearm is the extensor indicis. Like the little finger, the index finger has its own extensor muscle, in addition to getting a tendon from extensor digitorum.


Origin:
lateral epicondyle of the humerus and proximal shaft of the ulna
Supinator
Insertion:
proximal third of the radius

The last forearm muscle is the posterior compartment's supinator. Its supination is aided by the biceps brachii. The supinator is an interesting-looking muscle that spirals around the bones of the forearm. It originates on the lateral epicondyle of the humerus and proximal shaft of the ulna and winds around to insert on the proximal third of the radius on its posterolateral side.

As for innervations, the entire posterior arm and forearm are supplied by the radial nerve, but there are specifics. Brachioradialis and extensor carpi radialis longus are said to be supplied by the radial nerve, but once those two are innervated, the radial nerve splits into a superficial branch that is entirely cutaneous and a deep branch that supplies extensor carpi radialis brevis and the supinator. Once the radial nerve's deep branch emerges from the distal border of the supinator muscle, it is renamed as the posterior interosseous nerve, which supplies the other seven muscles of the posterior forearm.

Reading

Biel, *Trail Guide to the Body*, ch. 3, "Forearm & Hand."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 8, "Muscles of the Forearm and Hand."

Jarmey, *The Concise Book of Muscles*, ch. 8, "Muscles of the Forearm and Hand."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 7, "Muscles of the Forearm and Hand."

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Lecture 17

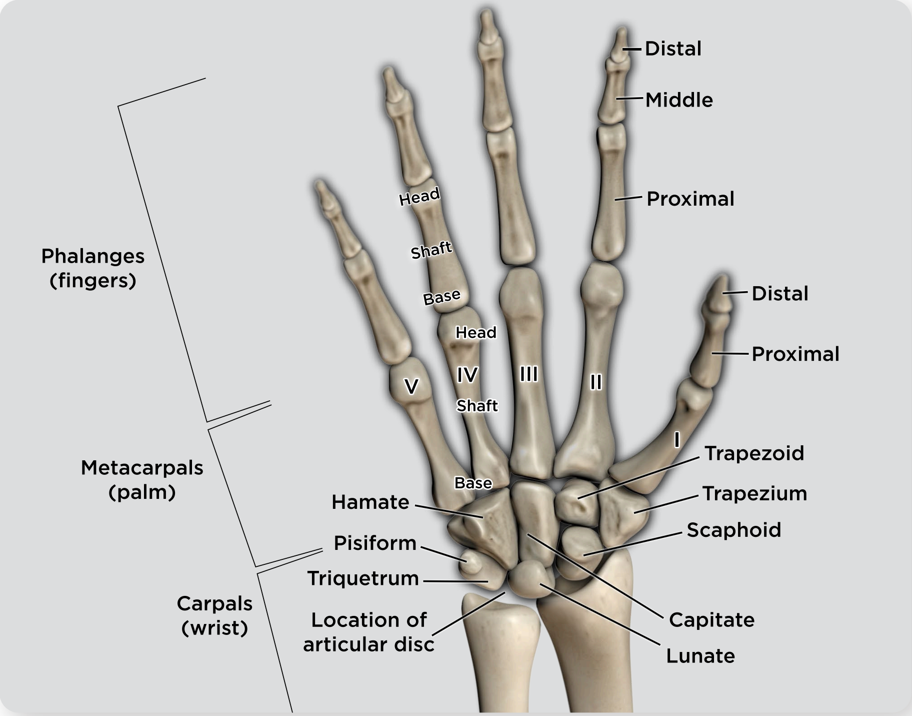
THE HAND AND HOW IT WORKS

The human hand holds some amazing architecture and is one of the anatomical features that separates us from all other animal life, except for our primate relatives. This lecture reviews the musculoskeletal anatomy of this evolutionary marvel that contributes so much to our humanity.

The Wrist and the Hand

The wrist holds a complex of eight small bones known as carpals, but only two of them have direct articulation with one of the two forearm bones. The radius widens at its distal end to form a joint with two of the eight carpals, while the ulna has an articular disc at its distal end that prevents it from direct articulation with any carpals.

The carpals are said to be in two rows of four. The proximal row contains the scaphoid at the lateral or thumb side, followed by the lunate and then the triquetrum medially. However, the fourth carpal in that proximal row, the pisiform, is not aligned next to the triquetrum; it's stacked on the triquetrum's anterior side. Typically, only the scaphoid and lunate articulate with the distal radius. Then, the distal row of four carpals are in a line from lateral to medial; they are the trapezium, trapezoid, capitate, and hamate.


Distal
Middle
Proximal
Distal
Proximal
Phalanges (fingers)
Head
Shaft
Base
Head
IV
Shaft
Base
V
III
II
I
Trapezoid
Trapezium
Scaphoid
Metacarpals (palm)
Hamate
Pisiform
Triquetrum
Carpals (wrist)
Location of articular disc
Capitate
Lunate

The scaphoid and trapezium, the lateral-most members of the proximal and distal row, respectively, each have a tubercle projecting from their anterior surface. Medially, the pisiform bone is stacked on the triquetrum in the proximal row, so it projects anteriorly—plus, the hamate has an anterior feature called its hook. The result is that laterally, the tubercles of the scaphoid and trapezium form the attachments of the deep part of the flexor retinaculum that forms the carpal tunnel, and the pisiform and hook of the hamate allow the medial attachment of the flexor retinaculum.

The carpal tunnel is an open passageway—a tube made by the flexor retinaculum's attachments to four of the carpals.

The three muscles with tendons that pass through the carpal tunnel are the flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus. Each tendon is in its own synovial sheath, and when irritated or inflamed, those sheaths can swell up, causing pressure within the carpal tunnel that compresses the nerve that travels with those tendons: the median nerve.

Moving distally from the carpals, the five metacarpals are not in a one-to-one ratio with the carpals since there are four carpals in the distal row. Each of the metacarpals has a proximal base, followed by its shaft, and the head of each metacarpal is distal. They don't have specific names. The metacarpals are instead referred to by Roman numerals: The most lateral on the thumb side is metacarpal one (I), and the most medial is metacarpal five (V) on the little finger side.

The head of each metacarpal—called a knuckle—articulates with the proximal phalanx in each digit. While the thumb has only two phalanges, a proximal and distal, each of the fingers has three phalanges: a proximal, middle, and distal. Each phalanx has a proximal base, a shaft, and a distal head. There are two other bones in each hand; two tiny sesamoid bones form at the head of the first metacarpal within the tendons of one of the muscles of the hand.

Carpal tunnel syndrome is a median nerve issue that's sometimes thought to be caused by overuse of the flexor muscles in the forearm, but it can occur after an injury or secondary to various medical conditions.

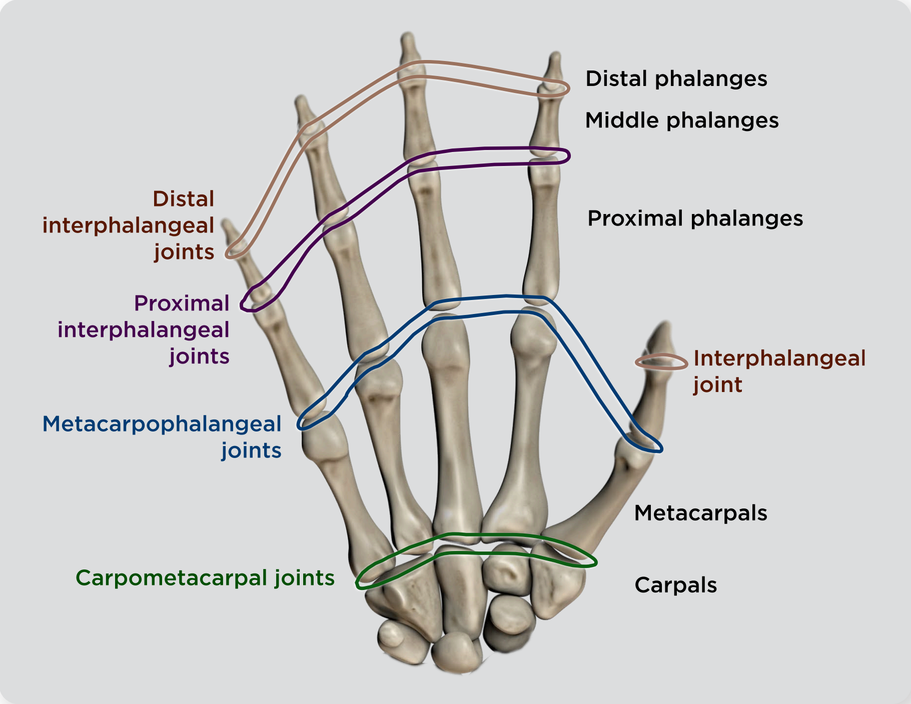
The wrist is anatomically known as the radiocarpal joint. It is condyloid or ellipsoidal in shape; the distal radius is slightly concave, and the scaphoid and lunate of the carpal group are convex. For this reason, the wrist is not a simple hinge joint, but allows flexion and extension as well as radial and ulnar deviation—all caused by muscles within the forearm.

However, like a hinge joint, there are radial and ulnar collateral ligaments at the wrist, like at the elbow. So you have to be specific as to whether you're referring to the radial collateral ligament of the wrist, for example, or of the elbow. The wrist's radial collateral ligament attaches the styloid process of the radius to the scaphoid and trapezium, which are the proximal and distal carpals on the lateral side, respectively. The ulnar collateral ligament of the wrist attaches the styloid process of the ulna to the triquetrum and the pisiform stacked on it.

Among the carpals, there are synovial planar joints: gliding joints that allow slight movements of carpals against their neighbors. Lots of intercarpal ligaments hold the bones of the wrist together. There are also radiocarpal and ulnocarpal ligaments to further support the wrist joint.

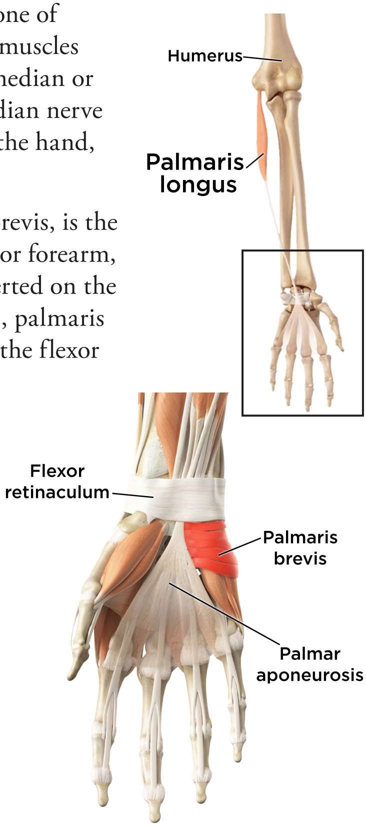
Most carpometacarpal joints are also planar gliding joints that don't allow much movement, but the carpometacarpal joint of the thumb is a saddle joint—a joint in which one bone acts like a saddle and the other fits into it as the rider. The result is our incredible primate thumb that can flex, extend, abduct, adduct, and rotate in opposition.

The metacarpophalangeal joints at the head of each metacarpal are ellipsoidal or condylar, since the head of each metacarpal is a rounded knob, and the base of each proximal phalanx is concave. That spooning shape allows more movement than a typical hinge joint, so there is not only flexion and extension but some side-to-side movement as well, allowing some abduction and adduction of the fingers. But once within a finger or the thumb, the interphalangeal joints are hinge joints with collateral ligaments that allow only flexion and extension.


Distal phalanges
Middle phalanges
Proximal phalanges
Distal interphalangeal joints
Proximal interphalangeal joints
Interphalangeal joint
Metacarpophalangeal joints
Metacarpals
Carpometacarpal joints
Carpals

The Muscles of the Hand

Intrinsic hand muscles are those completely within the hand, including their origin and insertion and therefore their action. There are three main muscle groups in the hand: three thenar muscles that make up the fleshy mass at the base of the thumb, the three hypothenar muscles that make up the fleshy mass at the base of the little finger, four muscles in the midpalmar area, and a tiny skin-wrinkling muscle that belongs to none of those groups. As with the anterior forearm, all muscles of the palmar hand are supplied by either the median or ulnar nerves. However, in the forearm, the median nerve supplies most muscles, whereas in the palm of the hand, the ulnar nerve supplies most muscles.



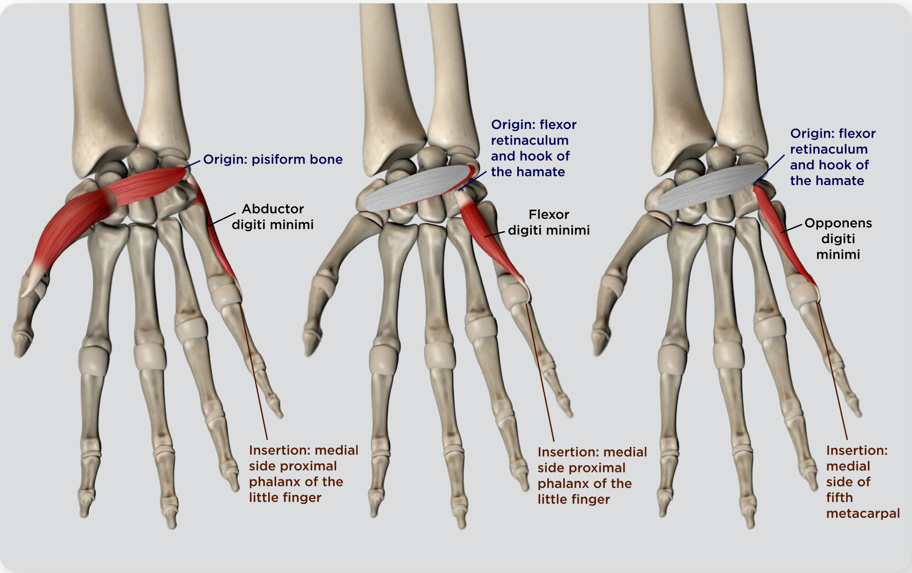
The tiny muscle of the palmar skin, palmaris brevis, is the counterpart of the variable muscle of the anterior forearm, palmaris longus. Whereas palmaris longus inserted on the flexor retinaculum and the palmar aponeurosis, palmaris brevis is a very small muscle that originates on the flexor retinaculum and palmar aponeurosis.

Strangely, like the muscles of facial expression, palmaris brevis inserts on skin—in this case, the skin on the medial edge of the palm. Its job is to help pick up the slack in the skin of the proximal palm when we perform opposition of our thumb and other fingers, especially the little finger. And while it's not variable like palmaris longus, it does vary in size; much of the time palmaris brevis is just a few tiny muscle strands passing transversely across the proximal wrist at the medial edge of the palm.

Palmaris brevis is innervated by the ulnar nerve—but immediately after supplying palmaris brevis, the ulnar nerve splits into a superficial branch that is entirely cutaneous to the medial palm and medial digits and a deep ulnar nerve that supplies most palmar muscles.

The three hypothenar muscles originate deep to palmaris brevis, taking origin from one or more of the carpals, the flexor retinaculum, or a combination of those. At the most medial edge of the palm is abductor digiti minimi*; its counterpart is pollex, the thumb. Abductor digiti minimi takes origin off the pisiform bone and the flexor carpi ulnaris tendon. The insertion of abductor digiti minimi is on the medial side of the base of the proximal phalanx of the little finger. Slightly lateral to it is flexor digiti minimi, which originates off the flexor retinaculum and the hook of the hamate and inserts on the medial side of the base of the little finger's proximal phalanx.

Deeper, but still originating on the flexor retinaculum and hook of the hamate, is the opponens digiti minimi; it inserts all along the medial aspect of the fifth metacarpal—the one for the little finger. The fibers of opponens digiti minimi are more obliquely oriented than the abductor or flexor digiti minimi, as you'd expect given its function, since opposition of the little finger means to touch it to the thumb. Abduction fans the pinkie finger out, and flexion bends it anteriorly.


Origin: pisiform bone
Abductor digiti minimi
Insertion: medial side proximal phalanx of the little finger
Origin: flexor retinaculum and hook of the hamate
Flexor digiti minimi
Insertion: medial side proximal phalanx of the little finger
Origin: flexor retinaculum and hook of the hamate
Opponens digiti minimi
Insertion: medial side of fifth metacarpal

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* Think of *digiti minimi* as a single phrase: "of the little finger."

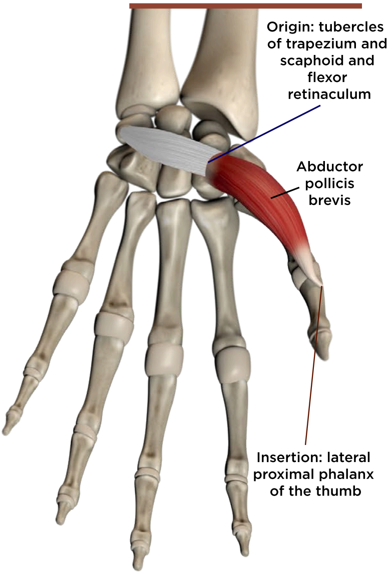
Not only does the little finger have flexor digiti minimi in the palm, in addition to its tendons from flexor digitorum superficialis and profundus, it also gets the extensor digiti minimi muscle from the posterior forearm in addition to its tendon from extensor digitorum. So, while it's no thumb, the little finger is capable of more movements than most other fingers.

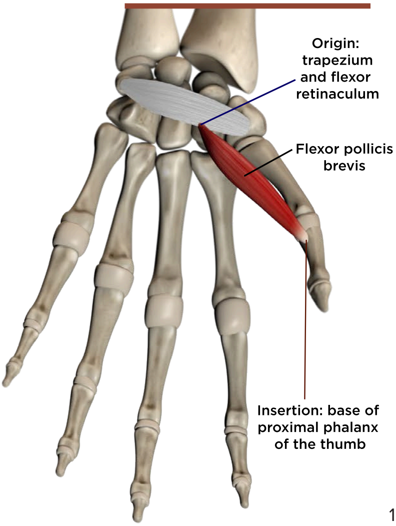
All of the hypothenar muscles are supplied by the deep branch of the ulnar nerve, which is the muscular branch after the superficial branch forks off to supply skin of the medial hand and digits.

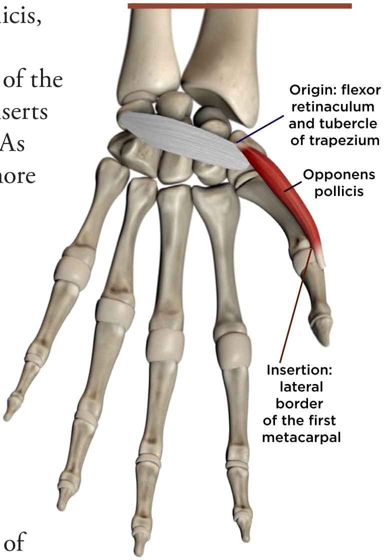
The three thenar muscles mirror the hypothenar muscles to some degree. They are abductor pollicis brevis, flexor pollicis brevis, and opponens pollicis.

As in the hypothenar group, abductor pollicis brevis is at the edge of the palm—this time the lateral edge. It originates on the tubercles of the scaphoid and trapezium and the flexor retinaculum and inserts on the lateral side of the base of the proximal phalanx of the thumb.

Flexor pollicis brevis is just medial to abductor pollicis brevis; it takes origin on the trapezium and flexor retinaculum and inserts on the base of the thumb's proximal phalanx. It has two heads: a superficial or lateral head and a deep or medial head. It's in those two heads that the sesamoid bones of the thumb grow and act as a guide to keep the tendon of flexor pollicis longus in position.


Origin: tubercles of trapezium and scaphoid and flexor retinaculum
Abductor pollicis brevis
Insertion: lateral proximal phalanx of the thumb

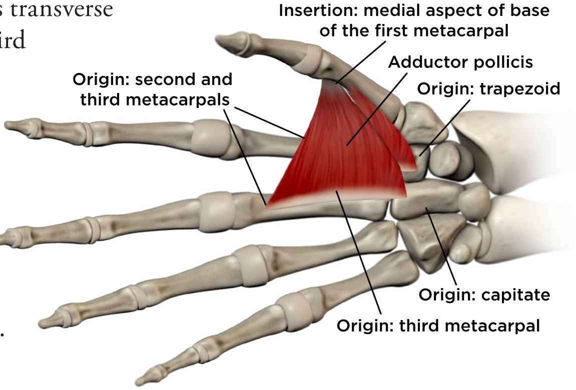

Origin: trapezium and flexor retinaculum
Flexor pollicis brevis
Insertion: base of proximal phalanx of the thumb

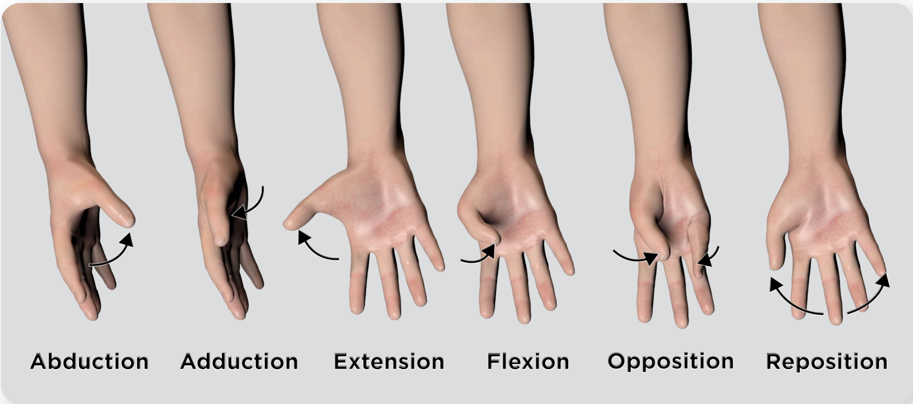

Origin: flexor retinaculum and tubercle of trapezium
Opponens pollicis
Insertion: lateral border of the first metacarpal

The final thenar muscle is the opponens pollicis, which is deep to the abductor pollicis brevis. Opponens pollicis originates on the tubercle of the trapezium and the flexor retinaculum and inserts on the lateral border of the first metacarpal. As with opponens digiti minimi, its fibers are more obliquely directed to allow opposition.

After passing through the carpal tunnel, the median nerve gives off its recurrent branch, which makes a U-turn just distal to the carpal tunnel and backtracks toward the thenar eminence. And while the abductor pollicis brevis, opponens pollicis, and the superficial head of the flexor pollicis brevis are supplied by this recurrent branch of the median nerve, the deep head of the flexor pollicis brevis is supplied by the deep branch of the ulnar nerve. This is because that deep branch of the ulnar nerve enters the palm medially, dives deep, and then takes a J-shaped course laterally across the palm, supplying numerous deep muscles before it terminates with its supply of the deep head of flexor pollicis brevis.

One more thumb muscle that isn't part of the thenar group is adductor pollicis. It is within the web of tissue between the index finger and the thumb. Adductor pollicis is said to have an oblique head originating off the second and third metacarpals as well as the capitate and trapezoid. Its transverse head originates off the third metacarpal. The heads converge to insert on the medial aspect of the base of the first metacarpal—the metacarpal of the thumb—and both are supplied by the deep branch of the ulnar nerve.


Insertion: medial aspect of base of the first metacarpal
Adductor pollicis
Origin: trapezoid
Origin: second and third metacarpals
Origin: capitate
Origin: third metacarpal



Abduction of the thumb takes it as far away from the palm as possible, at approximately a right angle to the palm. Pulling the thumb back to alignment with the palm is adduction. Fanning the thumb out in line with the palm is thumb extension, and bringing the thumb across the palm but close to the palm is flexion. Opposition of the thumb is a combination of abduction and flexion to the point where the thumb touches the little finger—though you can also touch the thumb to the other three fingers. Our all-important prehensile thumb gets no less than eight muscles, two of which have two heads, to enable its many essential movements.

Mummy-like wrappings on the anterior aspect of the fingers, known as osseofibrous tunnels, act like retinacula for the fingers and hold the flexor tendons to the phalanges. While there are no intrinsic muscles on the dorsum of the hand, the tendons of extensor digitorum are also of importance to muscles on the palm. This is because of their extensor expansions, also known as extensor hoods. These expanded tendons are continuous with the osseofibrous tunnels that wrap around the flexor tendons on the palmar side of the digits to keep them in place.

The three remaining muscles (or sets of muscles) in the mid-palm are the lumbricals, the palmar interossei, and the dorsal interossei.†

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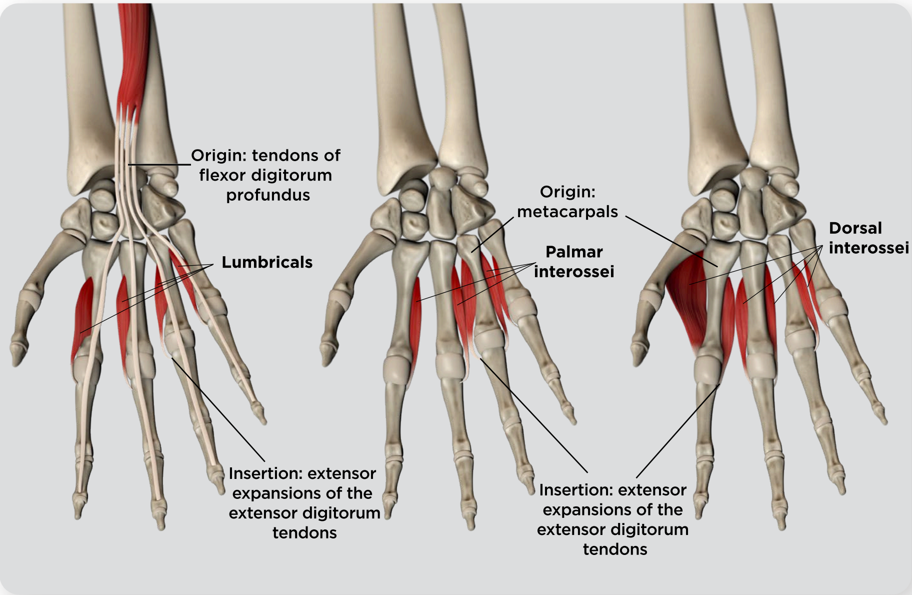
† *Interosseous* translates to "between bones," reflecting the depth of these muscles in the palm.

The four lumbricals originate on the tendons of flexor digitorum profundus; they insert on the lateral side of the extensor expansions of the extensor digitorum tendons.

The palmar interossei are three or four muscles (that's variable) that originate on the metacarpals and insert on the extensor expansions of the extensor digitorum tendons.

The four dorsal interossei are deeper than the palmar interossei and are best seen on the dorsum of the hand, between adjacent metacarpals. Each dorsal interosseous muscle has two heads from adjacent metacarpals that converge and insert on the extensor expansions.

All of these muscles—lumbricals and palmar and dorsal interossei—originate on the palm and cross the metacarpophalangeal joints on their anterior side. They flex those joints, but then the lumbricals and interossei all pass posteriorly to share attachment with the extensor digitorum muscles, so they also act to extend the interphalangeal joints.


Origin: tendons of flexor digitorum profundus
Lumbricals
Insertion: extensor expansions of the extensor digitorum tendons
Origin: metacarpals
Palmar interossei
Insertion: extensor expansions of the extensor digitorum tendons
Dorsal interossei

In addition, the palmar interossei adduct the fingers toward the middle finger, which is considered the central axis of the hand. The dorsal interossei abduct the other fingers away from the middle finger.

The web of the hand between the thumb and the palm is not just a single muscle; not only is the adductor pollicis muscle on the palmar side, but the posterior aspect of the web is the first dorsal interosseous muscle.

Both the palmar and dorsal interossei are supplied by the deep branch of the ulnar nerve. The median nerve has a motor branch that supplies the lateral two lumbricals—those of the index and middle fingers—while the medial two lumbricals are supplied by the deep branch of the ulnar nerve. The rest of the median nerve supplies the skin of the thumb and two and a half fingers, since the ring finger is half supplied by the median nerve, but its medial side is supplied by the superficial branch of the ulnar nerve.

Reading

Biel, *Trail Guide to the Body*, ch. 3, “Forearm & Hand.”

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 8, “Muscles of the Forearm and Hand.”

Jarmey, *The Concise Book of Muscles*, ch. 8, “Muscles of the Forearm and Hand.”

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 7, “Muscles of the Forearm and Hand.”

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Lecture 18

DIGITAL CADAVER LESSON: THE UPPER LIMB

This is a digital lecture that reviews what has been covered in lectures 13 through 17 using the Anatomage Table to move three-dimensionally through the human body. Watch the video to look beneath the skin and aid your understanding.

Reading

Herbert, Heisler, Chinn, Krabbenhoft, and Malakhova, *A Photographic Atlas for Anatomy & Physiology*, ch. 3, "The Skeletal System"; ch. 4, "The Muscular System" (cadaver images).

Martini, *Martini's Atlas of the Human Body*, Upper Limb sections (cadaver images).

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. C, "Upper Limb."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 10, "Clinical Anatomy of the Upper Limb."

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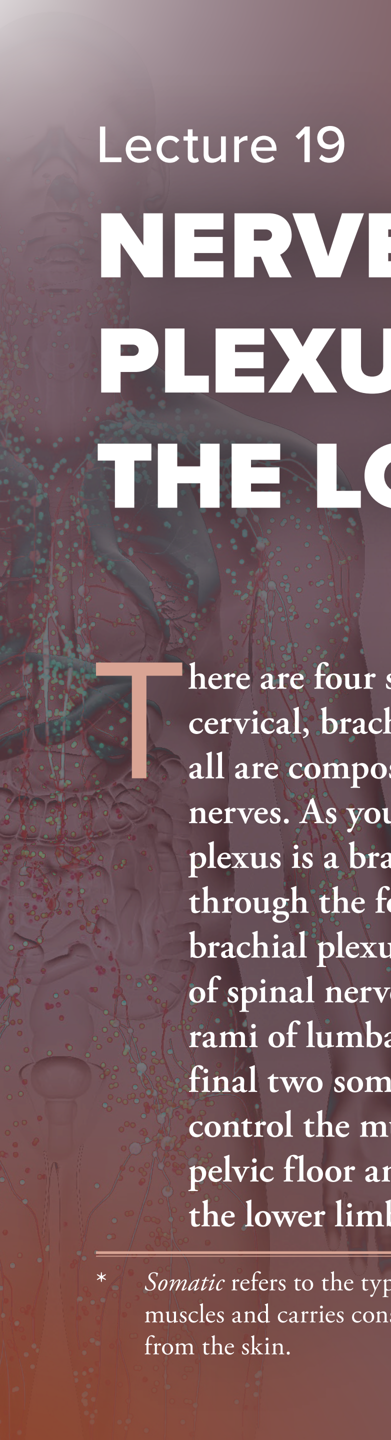

Lecture 19

NERVE PLEXUSES OF THE LOWER LIMB

There are four somatic* nerve plexuses—the cervical, brachial, lumbar, and sacral—and all are composed of the ventral rami of spinal nerves. As you learned previously, the cervical plexus is a braid of ventral rami from the first through the fourth cervical nerves, and the brachial plexus is composed of the ventral rami of spinal nerves C5 through T1. The ventral rami of lumbar and sacral nerves form the body's final two somatic nerve plexuses. Together, they control the muscles of the lower limb and the pelvic floor and relay conscious sensations from the lower limbs and genitalia.

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* *Somatic* refers to the type of nervous tissue that governs voluntary skeletal muscles and carries conscious sensations of touch, pain, and temperature from the skin.

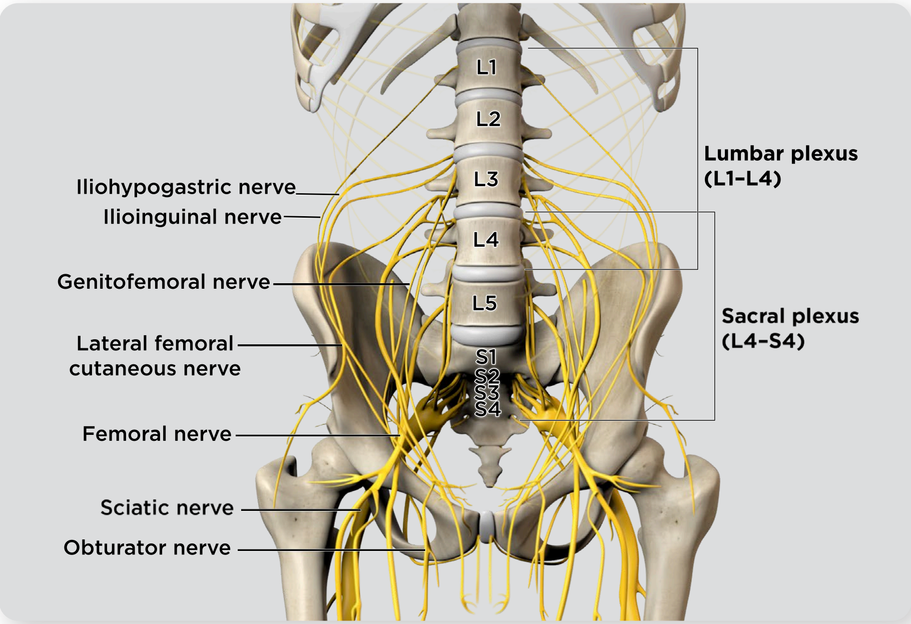
The Lumbar and Sacral Plexuses

Both the lumbar and sacral plexuses supply muscles and skin of the lower limb, share the ventral ramus of the fourth lumbar nerve, and form within or basically pass through a muscle that takes origin off the spinal column.

Because the fourth lumbar nerve belongs to both plexuses, some references combine the plexuses and refer to the entirety as a single lumbosacral plexus.

The lumbar plexus forms in the posterior abdominal wall, posterior to the psoas major muscle, and is composed of the ventral rami of the first through fourth lumbar nerves.

The sacral plexus forms in the posterior pelvis, on the anterior surface of the sacrum, where the ventral rami that form it pass between the fibers of the piriformis muscle. The sacral plexus is composed of the ventral rami of L4 through the fourth sacral nerve.


L1
L2
L3
L4
L5
S1
S2
S3
S4
Lumbar plexus (L1–L4)
Sacral plexus (L4–S4)
Iliohypogastric nerve
Ilioinguinal nerve
Genitofemoral nerve
Lateral femoral cutaneous nerve
Femoral nerve
Sciatic nerve
Obturator nerve

The Regions of the Lower Limb

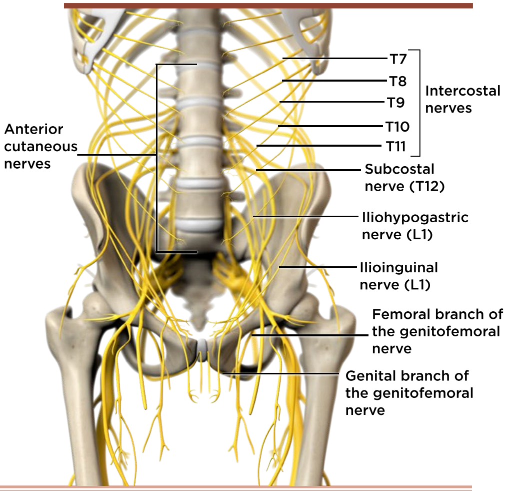
Like in the shoulder, the gluteal region of the hip contains numerous muscles, but they aren't wrapped in fascia, so they're not compartmentalized. Within the limb, the thigh is divided by fascial planes into three subdivisions: an anterior, posterior, and medial compartment.

Below the knee, the leg region is subdivided by fascia and the interosseous membrane between the tibia and fibula into an anterior, posterior, and lateral compartment. There are a few muscles on the dorsum of the foot, which is the top of the foot, and there are many muscles in the plantar region, or sole of the foot.

The Lumbar Plexus

Each lumbar nerve exits the spine through the intervertebral foramen located inferior to its respective lumbar vertebra. Then, each spinal nerve splits to form a dorsal ramus and a ventral ramus. The lumbar plexus is composed of the ventral rami of L1, L2, L3, and L4 that braid to form six nerves, as well as some tiny segmental branches. Unique to the lumbar plexus, compared to the other three somatic plexuses, is that all lumbar plexus nerves reach the skin to provide cutaneous innervation.

While the subcostal nerve—the name given to the ventral ramus of the 12th thoracic nerve†—doesn't belong to the lumbar plexus, it is usually the best place to start to identify the nerves of the lumbar plexus. This is because the 12th rib is easily felt in the posterior abdominal wall and can be used to identify the broad, flat subcostal nerve. From there, the ventral ramus of the first lumbar nerve can be identified.


T7
T8
T9
T10
T11
Intercostal nerves
Anterior cutaneous nerves
Subcostal nerve (T12)
Iliohypogastric nerve (L1)
Ilioinguinal nerve (L1)
Femoral branch of the genitofemoral nerve
Genital branch of the genitofemoral nerve

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† The term *intercostal* doesn't really fit, since the 12th rib is the final rib, so the accompanying nerve isn't actually between ribs.

Another structure that helps differentiate the major nerves off the lumbar plexus is the psoas major muscle—the landmark muscle of the lumbar plexus, as some nerves are easily differentiated by their relationship to the psoas major.

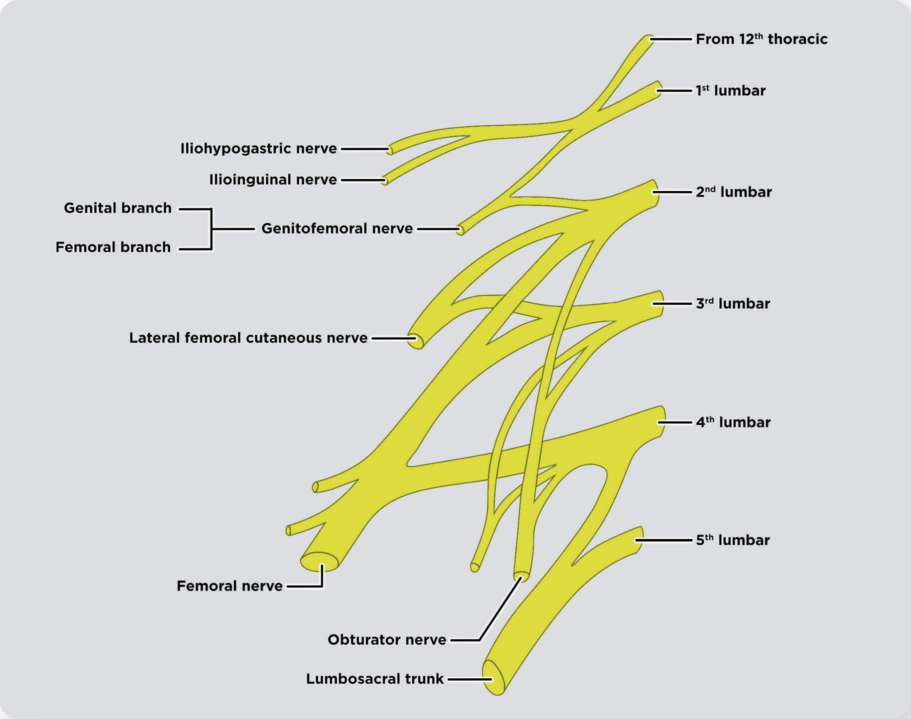
In the posterior abdominal wall, the L1 ventral ramus typically divides into two lumbar plexus branches: the iliohypogastric nerve and the ilioinguinal nerve. Like the subcostal nerve, these supply anterior and lateral abdominal wall muscles and have cutaneous branches to the skin.

As the iliohypogastric and ilioinguinal nerves course around the low torso, they pass between the transversus abdominis and internal oblique muscles and then eventually between the internal oblique and external oblique. Ultimately, the ilioinguinal nerve—but not the iliohypogastric—emerges from the muscle wall through a natural opening, known as the superficial inguinal ring, in the inferior border of the external oblique. This is the same opening that transmits the spermatic cord in males and the round ligament of the uterus in females.

The real braiding of the lumbar plexus begins when the ventral rami of L1 and L2 combine to form the genitofemoral nerve. Typically, the genitofemoral nerve emerges from the anterior surface of the psoas major muscle. After coming through the muscle, the genitofemoral nerve splits into a genital branch that passes medially and a femoral branch that passes laterally. The genitofemoral nerve is cutaneous in both sexes, but in males, part of it also supplies the cremaster muscle of the spermatic cord.

Progressing inferiorly, the ventral rami of L2 and L3 merge to form the lateral femoral cutaneous nerve, which is the only lumbar plexus nerve that is completely cutaneous in both sexes. As its name implies, it supplies the skin of the lateral aspect of the thigh.

The final two major nerves of the lumbar plexus are derived from braiding the ventral rami of L2, L3, and L4. The largest of the pair is the femoral nerve, which passes immediately lateral to the psoas major muscle and supplies most muscles of the anterior thigh. The femoral nerve also supplies skin of the anterior thigh and has a long cutaneous branch known as the saphenous nerve that continues below the knee and supplies the skin of the anterior and medial leg. This saphenous branch of the femoral nerve is the only branch of the lumbar plexus that has any function below the knee. All other skin below the knee is supplied by branches of the sacral plexus.


From 12th thoracic
1st lumbar
Iliohypogastric nerve
Ilioinguinal nerve
2nd lumbar
Genital branch
Genitofemoral nerve
Femoral branch
3rd lumbar
Lateral femoral cutaneous nerve
4th lumbar
5th lumbar
Femoral nerve
Obturator nerve
Lumbosacral trunk

The other branch derived from the braiding of L2 through L4 is the obturator nerve. It descends into the pelvis along the medial border of the psoas major muscle before passing through the large opening in the pelvis called the obturator foramen. From there, the obturator nerve reaches the medial compartment of the thigh, where it supplies most muscles, as well as skin on the medial aspect of the thigh.

Tiny segmental branches supply the psoas major muscle itself. Psoas major takes origin off the lumbar vertebrae and inserts on the lesser trochanter of the femur. Because it is located so medially in the posterior body wall, small segmental branches off ventral rami innervate psoas major.

The ventral ramus of L4 descends and links up with the ventral ramus of L5 to create a structure known as the lumbosacral trunk. It connects the lumbar plexus to the sacral plexus since L4 belongs to both.

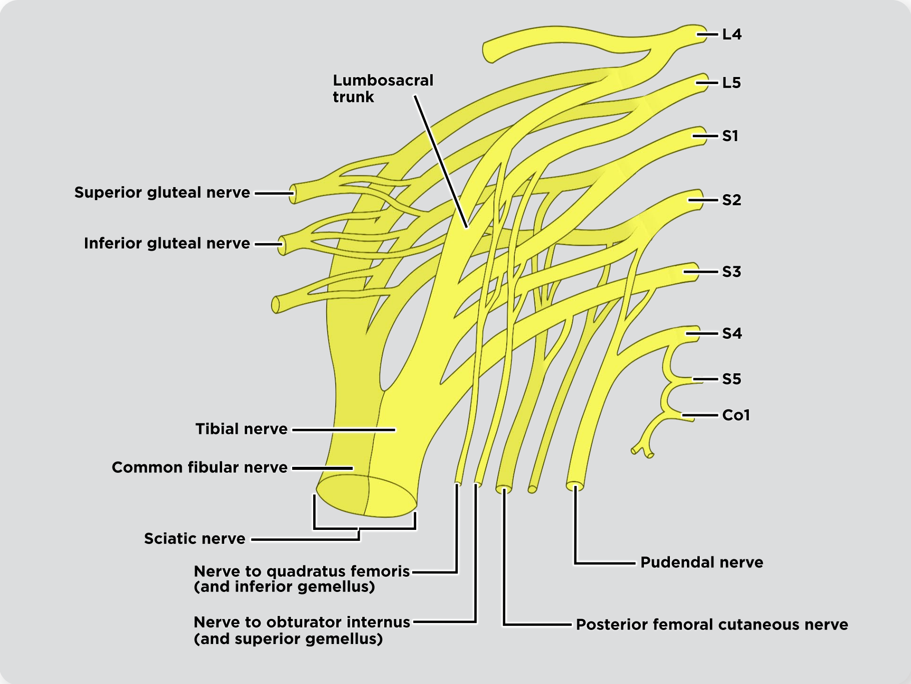
The Sacral Plexus

The sacral plexus forms on the anterior surface of the sacrum at the origin of the piriformis muscle—the landmark muscle of the sacral plexus. The lumbosacral trunk starts off the sacral plexus, but the four foramina on the anterior aspect of the sacrum transmit the ventral rami of S1, S2, S3, and S4 into the pelvis to continue the formation of the sacral plexus. Though there are five sacral nerves, the fifth does not typically have its own sacral foramen; it usually emerges between the sacrum and coccyx (tailbone). Likewise, there's a coccygeal nerve adjacent to the coccyx, but neither S5 nor the coccygeal nerve is involved with the sacral plexus. Typically, the ventral rami of six spinal nerves—L4 to S4—braid to form the eight nerve branches of the sacral plexus.

The spinal cord levels can be organized in four sets of threes. First, the ventral rami of L4, L5, and S1 braid to form two nerves of the sacral plexus: the superior gluteal nerve and the nerve to quadratus femoris. Next, the ventral rami of L5, S1, and S2 braid to form two nerves: the inferior gluteal nerve and the nerve to obturator internus. Then, the ventral rami of S1, S2, and S2 braid to form one nerve: the posterior femoral cutaneous. Finally, the ventral rami of S2, S3, and S4 braid to form the pudendal nerve. All but the ventral ramus of S4 merge to form the large sciatic nerve, which can be broken down to its two major subdivisions: the common fibular nerve and the tibial nerve.

Both the superior gluteal nerve and the nerve to quadratus femoris are composed of the first three levels of the sacral plexus: L4, L5, and S1. The superior gluteal nerve supplies two of the three gluteal muscles—gluteus medius and minimus—but also supplies the tensor of the fascia lata. As for the nerve to quadratus femoris, one of the muscles it supplies is the quadratus femoris of the deep gluteal region, but it also supplies the small muscle known as the inferior gemellus.

The second set of three cord levels—the ventral rami of L5, S1, and S2—combine to form the inferior gluteal nerve and the nerve to obturator internus. The inferior gluteal nerve's only responsibility is to supply the gluteus maximus muscle. The nerve to the obturator internus doesn't just supply the obturator internus muscle; it also supplies the small muscle known as the superior gemellus. None of those four nerves—not the superior or inferior gluteal nerves, nor the nerves to quadratus femoris or obturator internus—reach the skin for cutaneous distribution.


L4
L5
S1
S2
S3
S4
S5
Co1
Lumbosacral trunk
Superior gluteal nerve
Inferior gluteal nerve
Tibial nerve
Common fibular nerve
Sciatic nerve
Nerve to quadratus femoris (and inferior gemellus)
Nerve to obturator internus (and superior gemellus)
Pudendal nerve
Posterior femoral cutaneous nerve

The only nerve from the third set—the ventral rami of S1, S2, and S3—is the posterior femoral cutaneous nerve. It supplies no muscles and is the only branch of the sacral plexus that is entirely cutaneous. It supplies the posterior thigh down to the back of the knee.

The final set of three ventral rami is S2, S3, and S4, which braid to form the pudendal‡ nerve. This nerve is both cutaneous and motor to the perineum, which is the diamond-shaped region between the thighs. This body region is inferior to the pelvic diaphragm that supports the pelvic organs. The boundaries of the perineum are the pubic symphysis that links the two pelvic bones anteriorly, the two ischial tuberosities laterally, and the coccyx posteriorly.

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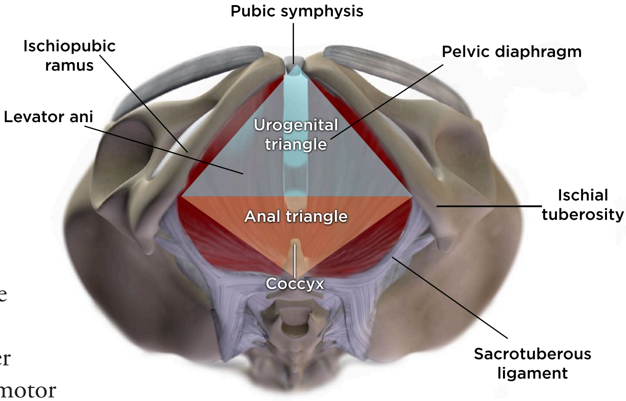
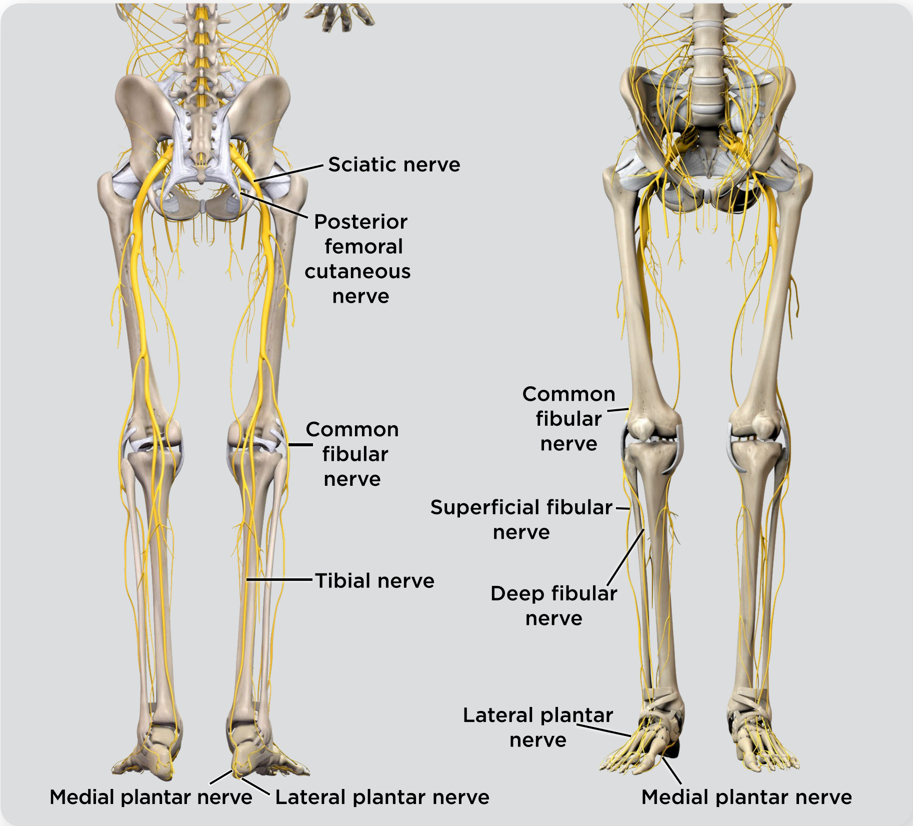
‡ The word *pudendal* comes from the Latin word for “shameful,” as in the 17th century, the area between the legs was a shameful zone.

And while those four bony landmarks outline the diamond-shaped region, an imaginary line taken between the ischial tuberosities can subdivide the perineum into a pair of triangles. The urogenital triangle is the anterior half of the region, and the anal triangle is the posterior half of the perineum. The urogenital triangle contains the external genitalia and the outlets of the urinary and reproductive systems, as well as the muscles, nerves, and vessels that control and supply those structures. The anal triangle contains the anal canal that serves as the outlet of the digestive system, as well as the muscle and neurovascular structures that supply structures in this region. The pudendal nerve off the sacral plexus is the origin for all nerves to this region, whether cutaneous to skin or motor to skeletal muscles.



The pudendal nerve gives off an inferior rectal branch that supplies the external anal sphincter—the voluntary skeletal muscle that allows us to control our bowels. It also gives off branches that supply the external urethral sphincter that controls the release of urine. The pudendal nerve also gives off branches that supply some of the muscles of the pelvic and urogenital diaphragms that support pelvic organs and prevent the prolapse of organs like the vagina and rectum. And it supplies muscles and sensations that help maintain sexual health and functions.

By far the largest nerve of the sacral plexus—in fact, the largest and longest nerve of the body—is the sciatic nerve. It is formed by the ventral rami of L4 to S3, so all levels of the sacral plexus except S4. But from the outset, even as it is forming, the sciatic nerve is really a combination of two nerves: the tibial and common fibular nerves.


Sciatic nerve
Posterior femoral cutaneous nerve
Common fibular nerve
Tibial nerve
Medial plantar nerve
Lateral plantar nerve
Common fibular nerve
Superficial fibular nerve
Deep fibular nerve
Lateral plantar nerve
Medial plantar nerve

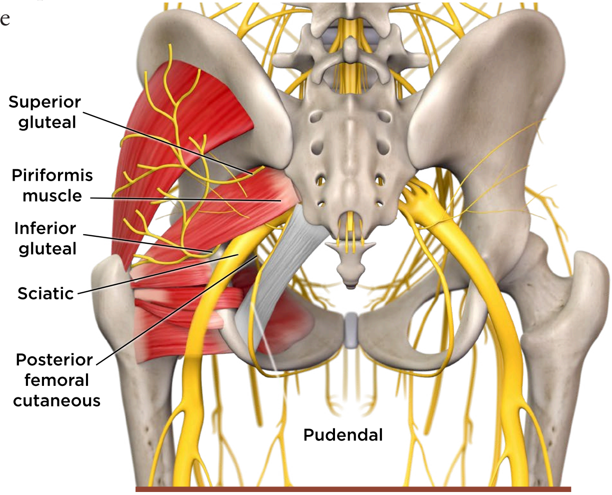
Both the tibial and common fibular nerves contribute to supplying the skin on the posterior leg. In terms of motor supply, the tibial portion of the sciatic nerve supplies the bulk of the hamstring muscles of the posterior compartment of the thigh and all muscles in the posterior compartment of the leg. As we will see, the tibial nerve splits at the ankle to create the medial and lateral plantar nerves, which together supply all muscles and skin of the sole of the foot.

All muscles below the knee are supplied by some branch of the sciatic nerve.

The common fibular nerve supplies a portion of one of the hamstring muscles, and then, just inferior and lateral to the knee, the common fibular nerve splits into a superficial fibular nerve and a deep fibular nerve. The superficial fibular nerve supplies the muscles of the lateral compartment of the leg as well as most of the skin of the anterolateral leg and dorsum of the foot. The deep fibular nerve supplies the muscles of the anterior compartment of the leg, the muscles on the dorsum of the foot, and a small patch of skin between the big toe and second toe.§

You really can't sort out the sacral plexus nerves within the pelvis where it forms on the anterior sacrum. It's not until you can see its branches in the gluteal region that you can differentiate most sacral plexus nerves. This is because all branches of the sacral plexus, as well as the piriformis muscle that originates on the anterior sacrum, exit the pelvis to reach the gluteal region. Then, the relationships of the sacral plexus nerves to the piriformis muscle help identify individual nerves. For example, the superior gluteal nerve reaches the gluteal region by passing superior to the piriformis muscle, while the inferior gluteal and pudendal nerves pass inferior to piriformis.

Once in the gluteal region, the pudendal nerve courses inferiorly to give off its inferior rectal branch in the anal triangle of the perineum, and then the pudendal nerve travels anteriorly to reach the structures of the urogenital triangle of the perineum.



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§ That branch is sometimes called the flip-flop nerve because that skin is where the tether in the open-style footwear sits.

The sciatic nerve is huge and also exits the pelvis inferior to the piriformis muscle but is accompanied for a distance by the much smaller posterior femoral cutaneous nerve. The nerve to obturator internus and nerve to quadratus femoris can't be seen without deep and detailed dissection, nor can the tiny segmental branches of the sacral plexus that supply piriformis.

Reading

Herbert, Heisler, Chinn, Krabbenhoft, and Malakhova, *A Photographic Atlas for Anatomy & Physiology*, ch. 5, "The Nervous System" (cadaver images).

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. D, "Lower Limb."

Ward, *Netter's Integrated Musculoskeletal System*, ch. 4, "Innervation of the Muscle Compartments"; ch. 11, "Clinical Anatomy of the Lower Limb."

TABLE OF CONTENTS

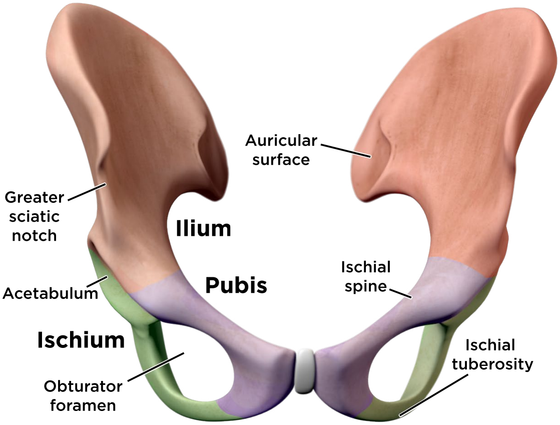
Lecture 20

THE MULTIPLEX PELVIS AND ITS HIP JOINT

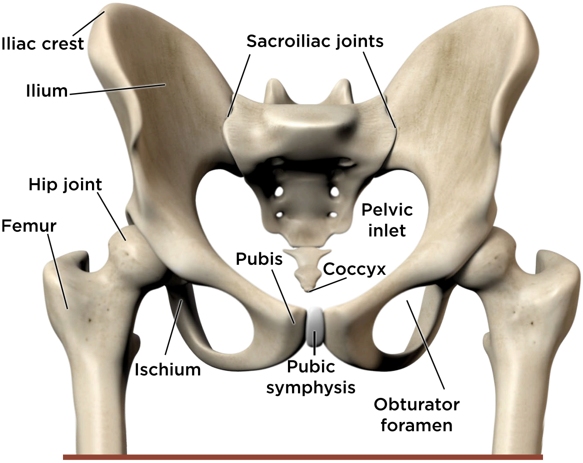
The pelvis is a complicated structure composed of the two hip bones of the appendicular skeleton as well as the sacrum and coccyx of the axial skeleton. And while you've learned about some muscles of the pelvis and pelvic floor in prior lectures, you have yet to learn about the pelvis itself in any detail.

The Pelvis and the Hip

Each hip bone is composed of three major parts: The ilium is the more bladelike upright portion, the ischium is the more inferior and posterior region that we sit on, and the pubis is the more anterior region.


Auricular surface
Greater sciatic notch
Ilium
Pubis
Ischial spine
Acetabulum
Ischium
Ischial tuberosity
Obturator foramen

In the pelvis, the two pubic bones are linked anteriorly at a cartilaginous joint known as the pubic symphysis. It's an amphiarthrotic joint; a pad of fibrocartilage links the two pubic bones, allowing just a bit of movement between the two hip bones.


Iliac crest
Sacroiliac joints
Ilium
Hip joint
Femur
Pelvic inlet
Pubis
Coccyx
Ischium
Pubic symphysis
Obturator foramen

In addition, the ilium of each hip bone is joined to the sacrum at a sacroiliac joint. The two sacroiliac joints are diarthrotic synovial joints, in which a capsule contains a joint cavity lined with synovial membrane. The articular cartilage of these joints doesn't unite each ilium with the sacrum. Rather, a capsule of connective tissue surrounds and unites the adjacent bones, allowing greater freedom of movement in the sacroiliac joints than in the pubic symphysis—but still not nearly as much movement as many other synovial joints.

On the ilium, there's a feature called the auricular* surface on the medial side of the posterior aspect of the bone that forms a joint with the corresponding auricular surface of the sacrum. Together these paired auricular surfaces form each sacroiliac joint, supported by anterior and posterior sacroiliac ligaments. These joints are how the two hip bones and the sacrum form the ringlike structure of the pelvis that protects and houses organs of the lower abdomen and the pelvis.

A single hip bone can be called a pelvic bone, but you can't call a single pelvic bone a pelvis.

But the auricular surface is just one of many landmarks on each hip bone. One of the more obvious features is the acetabulum, the socket of the ball-and-socket hip joint in which the head of the femur sits. The acetabulum faces laterally, since we hang our limbs on the lateral aspect of both the pectoral and the pelvic girdles.

Superior to the acetabulum is the relatively flat area of the ilium known as the iliac fossa. Its superior edge is known as the iliac crest, which terminates anteriorly in an anterior superior iliac spine (ASIS) and terminates posteriorly in a posterior superior iliac spine (PSIS). Just inferior to the ASIS is the anterior inferior iliac spine (AIIS), and just inferior to the posterior superior iliac spine is a posterior inferior iliac spine (PIIS). As in most other projections, these four prominences on the ilium serve as ligament or muscle attachment sites.

Inferior to the ilium is the ischium. The bony prominences on which we sit are the ischial tuberosities. They are also the major origins for the hamstring muscles of the posterior thigh. The ischium has a pointed posterior projection known as the ischial spine. Above the ischial spine is a feature called the greater sciatic notch, and the lesser sciatic notch is below the ischial spine.

A pair of ligaments, the sacrotuberous and sacrospinous ligaments, link the sacrum to the ischial tuberosity and the ischial spine, respectively. These ligaments turn the greater and lesser sciatic notches into the greater sciatic foramen and lesser sciatic foramen. These ligaments and the foramina they form are important to the integrity of the pelvis and relate the pelvis to the gluteal region and from there to the perineum.

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* *Auricular* means "ear-shaped" and comes from the Latin word for "ear."

Extending anteriorly from the ischial tuberosity is the ramus† of the ischium. The ischial ramus is a branchlike projection from the anterior surface of the ischial tuberosity that links with the inferior pubic ramus. Anterior to the acetabulum, the body of the pubic bone has both a superior pubic ramus and an inferior pubic ramus.

The pelvis is often the most obvious part of the skeleton in which male and female bony differences occur.

Together, the superior pubic ramus, body of the pubic bone, inferior pubic ramus, and ramus of the ischium help to surround and form the largest foramen in the body, the obturator foramen. Despite its large size in the skeleton, the obturator foramen is nearly completely covered by a membrane of connective tissue that is sandwiched by an obturator internus muscle on its deep side and obturator externus muscle on its superficial side. This leaves only a small portion of this large foramen open for passage of the obturator nerve, artery, and vein.

The body of the pubic bone has a prominence known as the pubic tubercle that is often more pronounced in biological males. The pubic tubercle and anterior superior iliac spine are the attachments for the structure known as the inguinal ligament, which is where the torso ends and the lower limb begins.

The Femur

The femoral head is a rounded knob that faces medially and has a depression in its center called the fovea capitis.‡ The femoral head constricts to a region called the neck of the femur.

Laterally, there is a large bony prominence called the greater trochanter, and more distally, medially, and slightly more posterior is the lesser trochanter. Of all the bony prominences in the human skeleton, trochanters are found only on the femur.

Anteriorly, running between the greater and lesser trochanter, there's an intertrochanteric line. Posteriorly, between the two trochanters is more of a raised ridge called the intertrochanteric crest.

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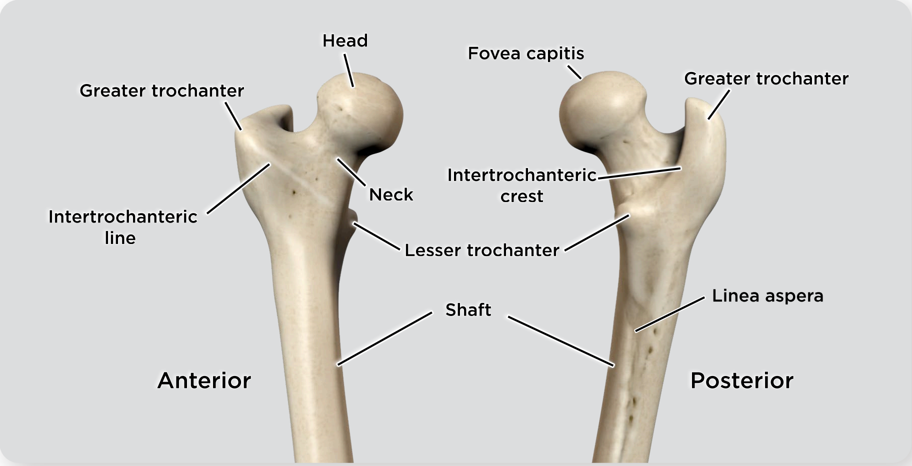
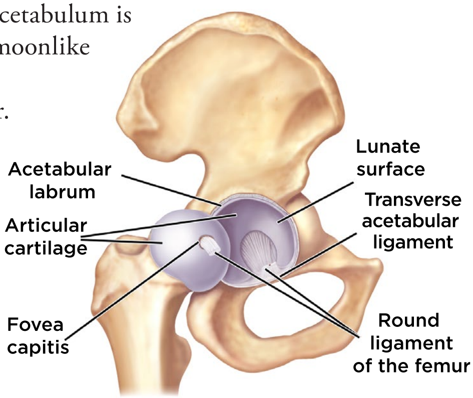
† *Ramus* means "branch."

‡ This is translated as the "pit on the head."


Head
Greater trochanter
Fovea capitis
Greater trochanter
Intertrochanteric crest
Neck
Intertrochanteric line
Lesser trochanter
Shaft
Linea aspera
Anterior
Posterior

The hip joint itself is different from the pubic symphysis and sacroiliac joints that help form the pelvis. The hip is a diarthrotic ball-and-socket joint between the acetabulum of the pelvic bone and the head of the femur. The rim of the acetabulum is not uniform throughout. At the anterior aspect, there's a deficiency known as the acetabular notch, which is bridged by a connective tissue band known as the transverse acetabular ligament. The socket is also deepened by a rim of cartilage known as the acetabular labrum that reaches around and clasps the head of the femur—unlike the glenoid labrum of the shoulder, which made the flat glenoid fossa broader but not deeper.

The actual articular surface of the acetabulum is known as the lunate surface for its moonlike shape; it is covered with articular cartilage, as is the head of the femur. Unlike the shoulder, the hip has an intracapsular ligament—which means it's within the joint capsule itself—known as the round ligament of the femur. It attaches the deep aspect of the acetabulum to the fovea capitis on the head of the femur.


Acetabular labrum
Lunate surface
Transverse acetabular ligament
Articular cartilage
Fovea capitis
Round ligament of the femur

The combination of this ligament within the capsule and the depth of the acetabulum—caused in part by the labrum—help make the hip quite stable.

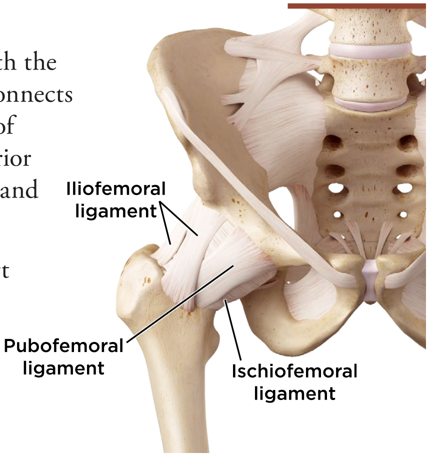
As a ball-and-socket joint, the hip is multiaxial, meaning it moves in three-dimensional space. Anterior motion at the hip, like kicking a ball with a straightened knee, is flexion. Moving the straight limb back—like winding up to kick—is extension. Lifting the lower limb out laterally, away from the midline, is abduction; pulling the thigh back toward the midline is adduction. Turning the toes in with a straight lower limb is medial rotation at the hip; pointing the foot out, directing the toes away from the midline, is lateral rotation. And while in no way as great a range of motion as at the shoulder, swinging the lower limb in an arc is circumduction.

The joint capsule is the sleeve of connective tissue that connects the bones in a diarthrotic joint, but not on their articular surfaces. In the hip joint, the capsule is composed of three ligaments that stabilize various aspects of the joint—and what's helpful is that they're named for the three parts of the pelvis. There's an iliofemoral ligament, a pubofemoral ligament, and an ischiofemoral ligament.

The iliofemoral ligament has the shape of an upside-down *Y*. It is anteriorly placed and passes from the anterior inferior iliac spine to the intertrochanteric line on the proximal anterior femur. The iliofemoral ligament is taut when standing and resists hyperextension to support our trunk without much additional muscle action at the hip. It is said to be the strongest ligament in the body.

The pubofemoral ligament blends with the inferior aspect of the iliofemoral. It connects the pubic bone to the inferior aspect of the intertrochanteric line on the anterior femur and limits excessive abduction and extension.

The ischiofemoral is the posterior part of the capsule. It spirals around from the ischium and attaches to the neck of the femur as its superior aspect. The ischiofemoral ligament also helps stabilize our standing position.

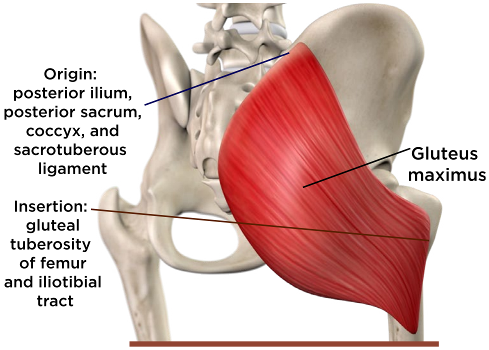


In addition, all three ligaments—iliofemoral, pubofemoral, and ischiofemoral—help limit medial rotation of the hip, which would cause the femur to turn internally. Together, they make the hip joint extremely stable—not only when standing, but also during our bipedal locomotion.

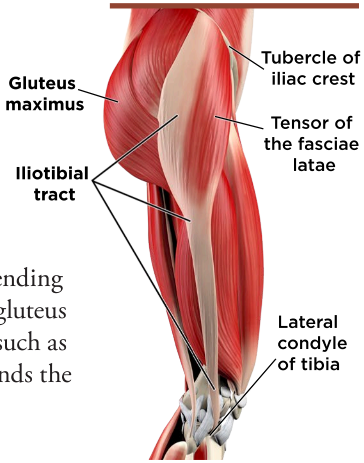
Muscles That Act on the Pelvis and Hip

Some of the muscles that act on the hip are the muscles of the gluteal region. There are not only three relatively large muscles with *gluteal* in their name but also a series of five smaller muscles in the deep gluteal region.

Gluteus maximus has a broad origin along the outer ilium, the posterior aspect of the sacrum and coccyx, and the sacrotuberous ligament, which connects the sacrum to the ischial tuberosity. The gluteus maximus inserts partly on the gluteal tuberosity on the femur as well as the iliotibial tract, often called the IT band.


Origin: posterior ilium, posterior sacrum, coccyx, and sacrotuberous ligament
Gluteus maximus
Insertion: gluteal tuberosity of femur and iliotibial tract

We wear the equivalent of a fascial stocking deep to the skin of the entire lower limb. The fascia lata is the region of this fascial stocking deep to the skin of the thigh, and not only does it help create the compartments of the thigh, but the fascia lata has a vertical thickening in its lateral aspect: the iliotibial tract. The lateral part of gluteus maximus inserts into that iliotibial tract thickening, in addition to its insertion on the gluteal tuberosity of the femur.


Tubercle of iliac crest
Gluteus maximus
Tensor of the fasciae latae
Iliotibial tract
Lateral condyle of tibia

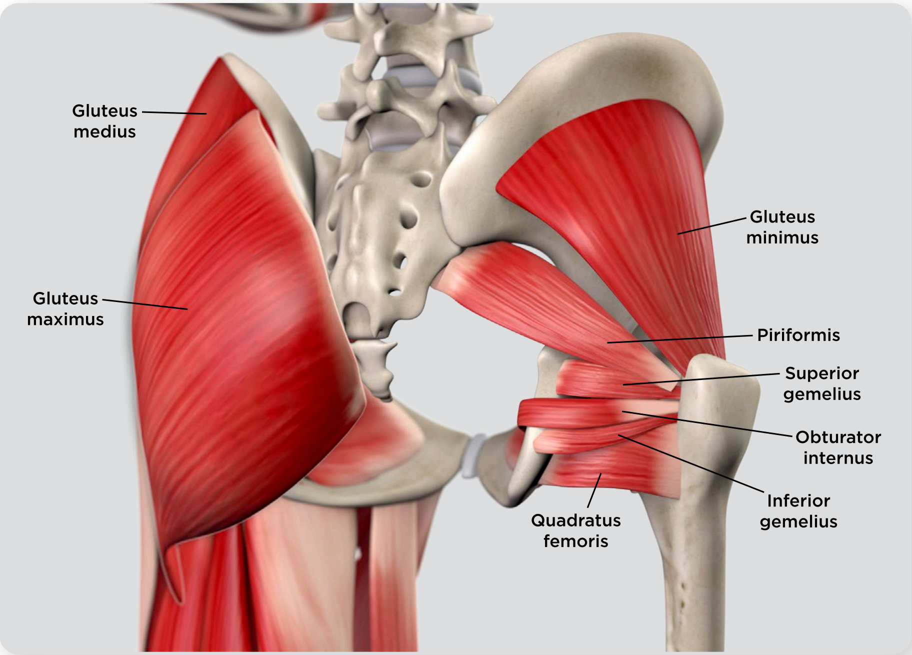
Due to its size, position, and fiber direction, the gluteus maximus has varied actions, depending on what part of it is being used. As a whole, gluteus maximus is the major extensor of the thigh, such as when kicking the thigh back, but it also extends the trunk, such as when climbing stairs.

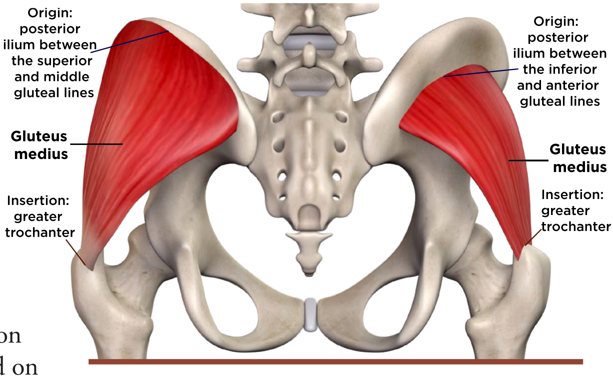
Because its fibers are directed laterally, toward its insertion on the iliotibial tract and femur, gluteus maximus also helps laterally rotate the thigh at the hip joint—as when pointing your toes away from the body. When used alone, the upper fibers can help the other gluteal muscles abduct the thigh, while the lower fibers can help the muscles of the medial thigh adduct the thigh.

The inferior gluteal nerve off the sacral plexus supplies gluteus maximus—and that is its sole job. The inferior gluteal nerve exits the pelvis to reach the gluteus maximus by passing inferior to the piriformis muscle, thus its name.

Deep to the lateral aspect of gluteus maximus are gluteus medius and gluteus minimus. Both are supplied by the superior gluteal nerve, which exits the pelvis above the piriformis muscle.

Compared to gluteus maximus, the gluteus medius is also more superiorly placed—which is why it can be seen peeking out from superior to gluteus maximus.


Gluteus medius
Gluteus maximus
Gluteus minimus
Piriformis
Superior gemelius
Obturator internus
Inferior gemelius
Quadratus femoris


Origin: posterior ilium between the superior and middle gluteal lines
Gluteus medius
Insertion: greater trochanter
Origin: posterior ilium between the inferior and anterior gluteal lines
Gluteus medius
Insertion: greater trochanter

Both gluteus medius and gluteus minimus take origin on the outer surface of the ilium from what are called its gluteal lines. And both insert on the greater trochanter of the femur—though the gluteus medius insertion is more laterally placed on the femur's greater trochanter, while the gluteus minimus insertion is a bit more anterior on the greater trochanter.

As a result of similarities in their origins and insertions, gluteus medius and minimus have identical actions: Both help stabilize the hip joint when we're standing, especially when we raise our opposite limb. Both also perform abduction of the femur at the hip joint as well as aid in medial rotation of the lower limb at the hip.

The superior gluteal nerve, artery, and vein all dive between gluteus medius and gluteus minimus, serving gluteus medius from its deep side but supplying gluteus minimus from its superficial side—which is rare in anatomy. After serving gluteus medius and minimus, the superior gluteal nerve continues laterally to meet the tensor of the fascia lata—and those are the only three muscles served by the superior gluteal nerve.

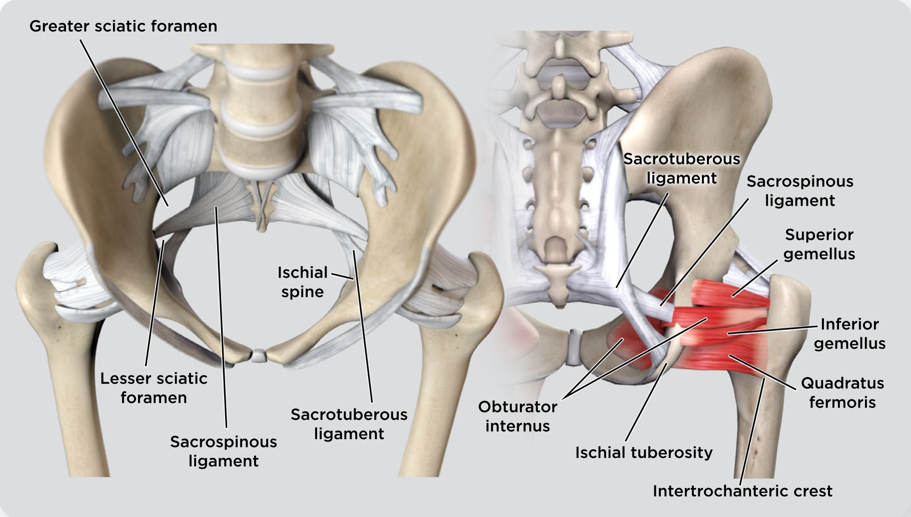
The five remaining muscles of the gluteal region are deep to the gluteus maximus. From superior to inferior, they are piriformis, superior gemellus, obturator internus (at least its tendon of insertion), inferior gemellus, and quadratus femoris.

Piriformis is a triangle-shaped muscle with its base taking origin off the anterior sacrum and slightly on the sacrotuberous ligament. The apex of its triangular shape is its insertion on the greater trochanter of the femur, which it reaches by traveling out of the pelvis through the greater sciatic foramen—which is formed by the addition of the sacrotuberous and sacrospinous ligaments to the pelvis. Because piriformis attaches to the superior aspect of the greater trochanter, it can abduct the thigh, especially when the hip is flexed, but can also laterally rotate the hip. It is innervated by small segmental branches of the sacral plexus, which form on the anterior surface of the sacrum from the braiding of ventral rami of L4 to S4.

The obturator internus muscle originates on the deep side of the rim of the pelvis's obturator foramen as well as from the membrane that covers most of the foramen. The tendon of obturator internus leaves the pelvis through the lesser sciatic foramen, formed by the crossing of the sacrotuberous and sacrospinous ligaments.

The superior gemellus muscle flanks the superior edge of the tendon of obturator internus, and the inferior gemellus muscle flanks its inferior edge. Together, the three muscles insert into the medial aspect of the greater trochanter, near the intertrochanteric crest that runs posteriorly between the greater and lesser trochanters.

In the body, these three appear almost as one wide muscle with a single central tendon. The superior gemellus originates off the ischial spine, and the inferior gemellus originates off the superior edge of the ischial tuberosity. They don't pass through the lesser sciatic foramen; they originate on its lateral edge.


Greater sciatic foramen
Ischial spine
Lesser sciatic foramen
Sacrospinous ligament
Sacrotuberous ligament
Sacrotuberous ligament
Sacrospinous ligament
Superior gemellus
Inferior gemellus
Quadratus fermoris
Obturator internus
Ischial tuberosity
Intertrochanteric crest

Inferior to the inferior gemellus is the quadratus femoris muscle. It originates on the lateral edge of the ischial tuberosity and inserts on the intertrochanteric crest. Together, all of these muscles—piriformis, superior gemellus, obturator internus, inferior gemellus, and quadratus femoris—laterally rotate the hip joint and help stabilize it.

Reading

Biel, *Trail Guide to the Body*, ch. 6, "Pelvis & Thigh."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 9, "Muscles of the Hip and Thigh."

Delavier, *Strength Training Anatomy*, ch. 6, "Buttocks."

Dimon, *Anatomy in Action*, ch. 11, "The Hips."

Jarmey, *The Concise Book of Muscles*, ch. 9, "Muscles of the Hip and Thigh."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 8, "Muscles of the Hip and Thigh."

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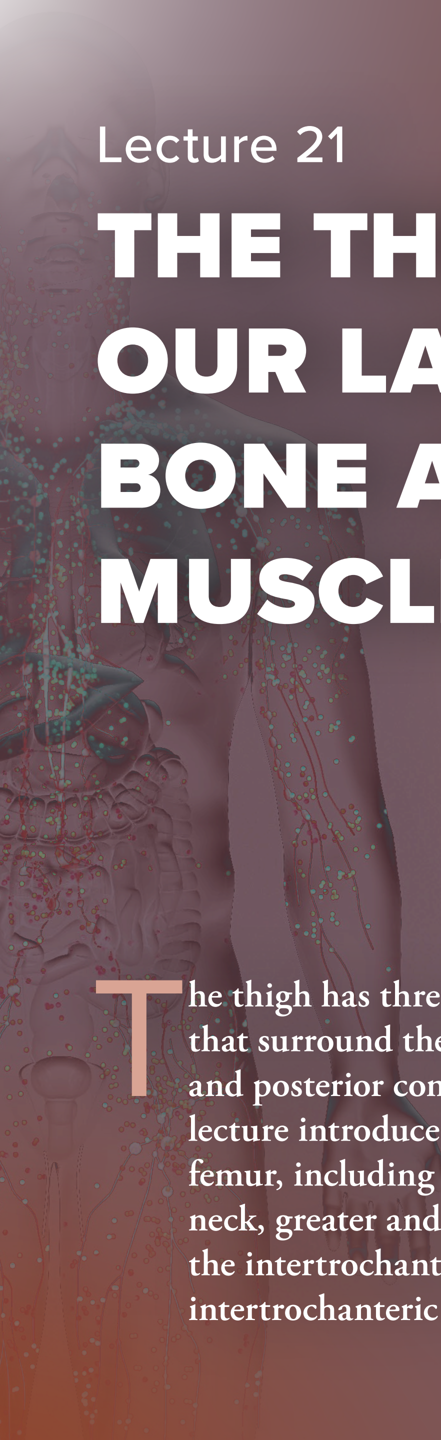


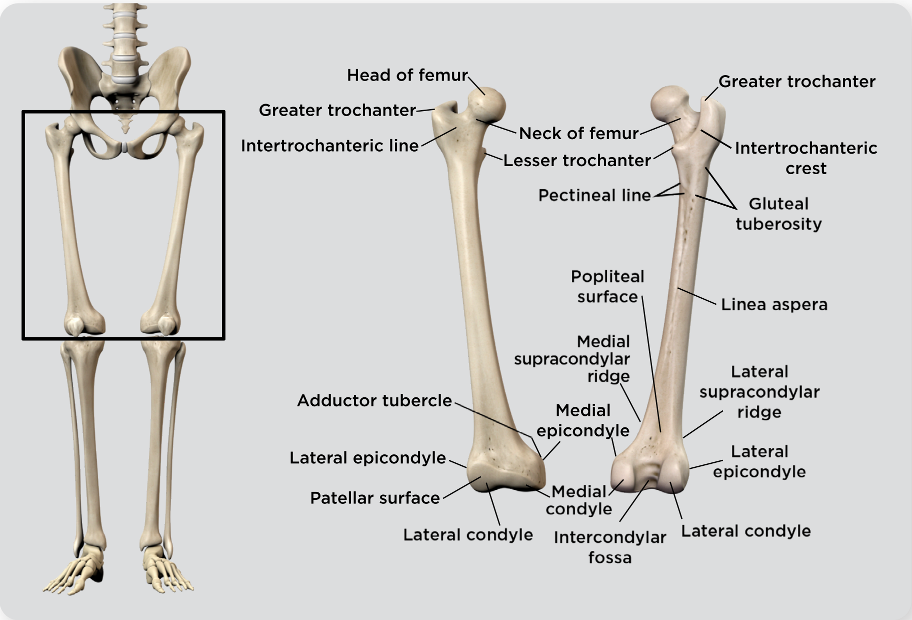
Lecture 21

THE THIGH: OUR LARGEST BONE AND ITS MUSCLES

The thigh has three compartments of muscles that surround the femur: an anterior, medial, and posterior compartment. The previous lecture introduced the proximal aspect of the femur, including the femoral head, femoral neck, greater and lesser trochanters, and the intertrochanteric line anteriorly and intertrochanteric crest posteriorly.

Anatomy Relevant to the Thigh

Continuing with the study of the femur, the anterior shaft of the bone is smooth, but posteriorly, the femoral shaft bears a long ridge called the linea aspera. It is a major muscle attachment site for one or more muscles in each of the three compartments of the thigh. The linea aspera begins as the union of two other landmarks on the posterior proximal femur: the pectineal line medially and the gluteal tuberosity—which is part of the insertion for the gluteus maximus—laterally. The pectineal line and gluteal tuberosity come together like the arms of the letter *Y* to form the linea aspera that passes down the posterior femur. Where the linea aspera terminates, it diverges into the medial and lateral supracondylar ridges, and between them is a smooth spot known as the popliteal* surface of the femur.


Head of femur
Greater trochanter
Intertrochanteric line
Neck of femur
Lesser trochanter
Pectineal line
Greater trochanter
Intertrochanteric crest
Gluteal tuberosity
Popliteal surface
Linea aspera
Medial supracondylar ridge
Adductor tubercle
Medial epicondyle
Lateral supracondylar ridge
Lateral epicondyle
Lateral epicondyle
Patellar surface
Medial condyle
Lateral condyle
Intercondylar fossa
Lateral condyle

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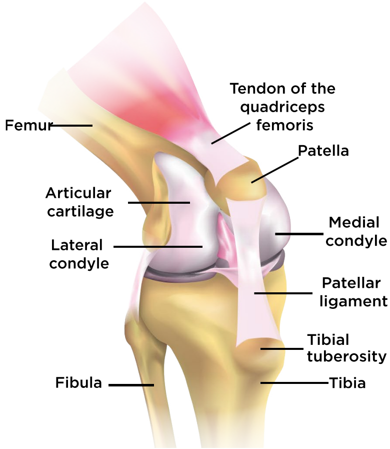
* The area posterior to the knee is known as the popliteal region.

Just distal to the popliteal surface are a pair of smooth, rounded prominences on the femur called the medial and lateral femoral condyles. Between them is a deep depression known as the intercondylar fossa, while superior to each femoral condyle are prominences called the medial and lateral epicondyles—as is seen on the humerus near the elbow. The medial epicondyle is topped by the adductor tubercle.

The femoral condyles merge in a smooth, flat area on their anterior surfaces called the patellar surface. This is where the patella, or kneecap, articulates with the femur.

The patella is a triangular bone with its flat base directed superiorly and its apex pointed inferiorly. Its posterior surface has a pair of smooth facets: a smaller one for the medial condyle of the femur and a larger one for the lateral femoral condyle.

The tibia has a medial and lateral condyle on the relatively flat area, sometimes called the tibial plateau, at its proximal end. On the anterior aspect of the proximal tibia is a bump called the tibial tuberosity, which is easily felt on your own shin.



The head of the fibula can also be felt laterally behind your knee, especially if you're sitting down and your knee is flexed. These landmarks relate to the knee joint. However, at the knee, the femur articulates with only the patella and the tibia; the fibula does not have a bony articulation with the femur. The fibula attaches to a facet on the lateral aspect of the proximal tibia.

As you learned in the previous lecture, the fascia lata encases the muscles of the thigh and has a vertically oriented thickening—the iliotibial tract, or IT band—in its lateral aspect. The iliotibial tract adds to the strength and stability of the thigh and knee, especially when the opposite foot is raised.

Gluteus maximus has part of its insertion on this iliotibial tract, but another muscle on the anterolateral aspect of the hip—the tensor of the fascia lata, also known as the tensor fasciae latae—is also attached to the iliotibial tract. At the knee, the iliotibial tract attaches to the lateral condyle of the tibia in an area that gets the eponym Gerdy's tubercle.

The fascia lata is also bound to other thickened sheets of connective tissue that dive down to the linea aspera on the posterior femur, separating and forming the three compartments of the thigh. As in the upper limb, these fascial planes not only compartmentalize but also provide intervals in which larger nerves and blood vessels travel—to either pass through the thigh or give off branches that supply the muscles.

The Anterior Thigh

The anterior compartment contains the four muscles of the quadriceps femoris group as well as four other muscles, depending on which reference you consult.†

Most of the anterior compartment muscles are supplied by the femoral nerve, which is composed of lumbar plexus ventral rami L2, L3, and L4. And any of these muscles that cross the anterior hip will flex the hip, while those that cross the anterior knee will extend the knee, among other functions.

The most proximal anterior compartment muscle is psoas major, the muscle posterior to and around which the lumbar plexus forms and distributes in the posterior abdominal wall. Psoas major originates from the 12th thoracic vertebra and the five lumbar vertebrae and ends up in a dual insertion on the lesser trochanter of the femur. A second muscle—the iliacus—takes origin from the iliac fossa of the hip bone and blends with the psoas major, and together they insert on the lesser trochanter. Because the two muscles are indistinguishable at their insertion, many references refer to these collectively as the iliopsoas.

Because psoas major originates on the lumbar spine, it can help flex the trunk at the low back, whereas iliacus cannot. But both cross the anterior aspect of the hip joint, so together they flex the hip, as when raising your lower limb to step up to the next stair.

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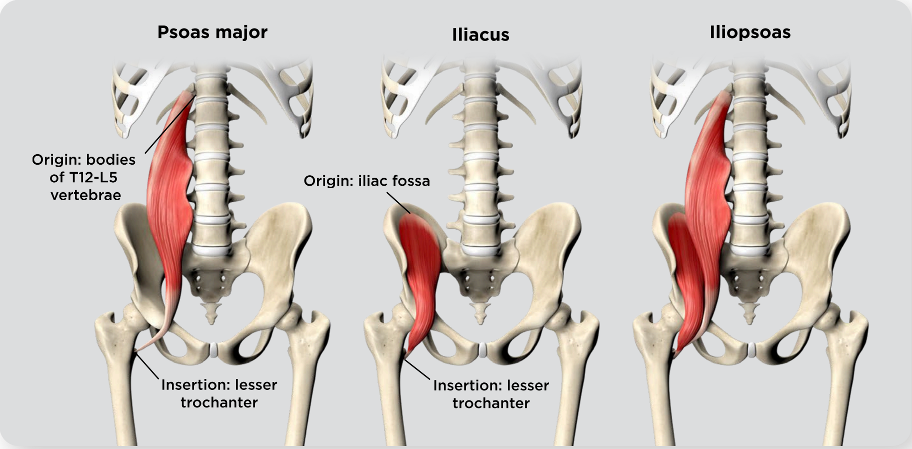
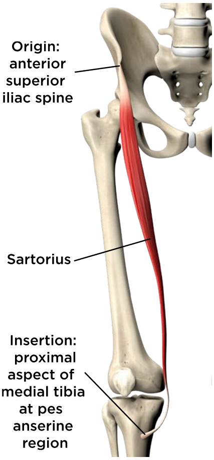
† Some consider the tensor muscle of the fascia lata to be with the gluteal region.


Psoas major
Iliacus
Iliopsoas
Origin: bodies of T12-L5 vertebrae
Insertion: lesser trochanter
Origin: iliac fossa
Insertion: lesser trochanter

In terms of innervation, iliacus is supplied by the femoral nerve itself, while psoas major is supplied by small segmental branches off the ventral rami of the lumbar plexus, due to its proximity near the midline of the body.

Only around 40% of people have a psoas minor. But when present, psoas minor appears as a small version of psoas major sitting on the major's anterior surface. It typically originates from T12 and L1 only and inserts on the anterior pelvic bone near where the ilium and pubis meet. It doesn't insert with the iliopsoas. Although they are considered muscles of the anterior thigh, psoas major and iliacus are deep—and really more located in the abdomen than in the lower limb. They are often called our deep hip flexors.

Once within the anterior thigh, the most superficial—and therefore most obvious—muscle is sartorius, which originates from the anterior superior iliac spine and then takes an oblique course to attach to the medial aspect of the proximal tibia, so it crosses both the hip joint and the knee joint. Its attachment to the medial tibia is in a spot known as the *pes anserine*, from the Latin for the "goose's foot."‡


Origin: anterior superior iliac spine
Sartorius
Insertion: proximal aspect of medial tibia at pes anserine region

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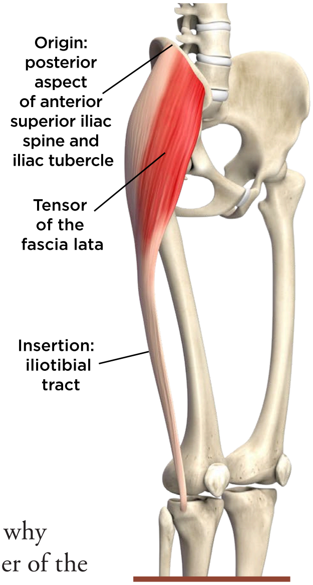
‡ This triple insertion where three tendons converge has been likened to the three toes of a goose.

Sartorius is supplied by the femoral nerve. It's the muscle that you use when you cross your legs to put your lateral leg on top of your opposite knee. During that motion, you are flexing, abducting, and laterally rotating at the hip joint while flexing and slightly mediately rotating your knee joint.

> Sartorius is the longest muscle in the body. In fact, the cells within a muscle can be nearly as long as the entire muscle itself, so some of the cells within sartorius are the longest muscle cells in the body—at nearly a foot in length.

Another muscle that could be said to cross both the hip and the knee is the tensor of the fascia lata. The muscle belly originates from the lateral edge of the anterior superior iliac spine and a pronounced region on the lateral ilium known as the iliac tubercle and inserts on the iliotibial tract—which does cross the knee—but the muscle belly only acts on the hip joint and to tighten the iliotibial tract, thereby supporting the hip, thigh, and lateral knee. Because it is lateral to the hip joint, the tensor of the fascia lata can assist in hip abduction, and because it's anteriorly placed, it can assist in hip flexion as well as medial rotation of the hip.

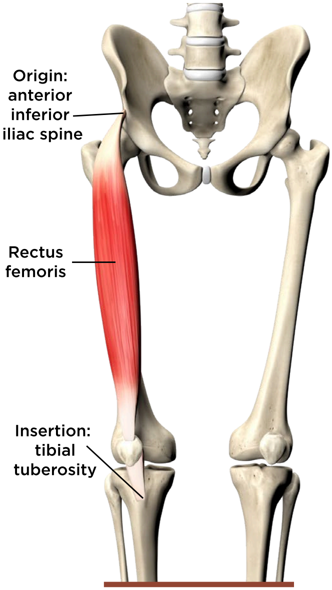

Origin: posterior aspect of anterior superior iliac spine and iliac tubercle
Tensor of the fascia lata
Insertion: iliotibial tract

The innervation of the tensor of the fascia lata is the superior gluteal nerve, which breaks the compartment innervation rules of the thigh and is why some references consider this muscle to be a member of the gluteal group.

The last four muscles in the anterior thigh constitute the quadriceps femoris group: rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius. Though they all have different origins, all four of these muscles converge on a single tendon that crosses the anterior aspect of the knee joint.

It's in this tendon that the patella forms, and then the tendon—now better called a ligament§—continues distal to the knee joint to attach to the tibial tuberosity. This ligament is called the patellar ligament.

The rectus femoris also crosses the hip joint and is the only one of the quads that does. Rectus femoris originates on the anterior inferior iliac spine and partly on the rim of the acetabulum, crosses the anterior hip joint, and then inserts by the patellar ligament onto the tibial tuberosity, crossing the anterior knee joint. It is used when thigh flexion and knee extension are needed together, such as when kicking a ball. The other three members of the quadriceps group originate from the femur itself and, since they don't cross the hip, can only act in knee extension.


Origin: anterior inferior iliac spine
Rectus femoris
Insertion: tibial tuberosity

Vastus lateralis originates along the intertrochanteric line, the greater trochanter's inferior border, the gluteal tuberosity, and all along the lateral aspect of the linea aspera. So although it is a member of the anterior compartment of the thigh, the origin of vastus lateralis begins posteriorly on the femur, passes deep to the iliotibial tract, and joins the other three quadriceps femoris muscles to insert on the tibial tuberosity.

Vastus lateralis is the largest muscle in the body and can be seen and felt all along the lateral thigh.

Vastus medialis originates off the intertrochanteric line and medial aspect of the linea aspera, but the bulge of its muscle appears much closer to the knee, where it joins the quadriceps tendon.

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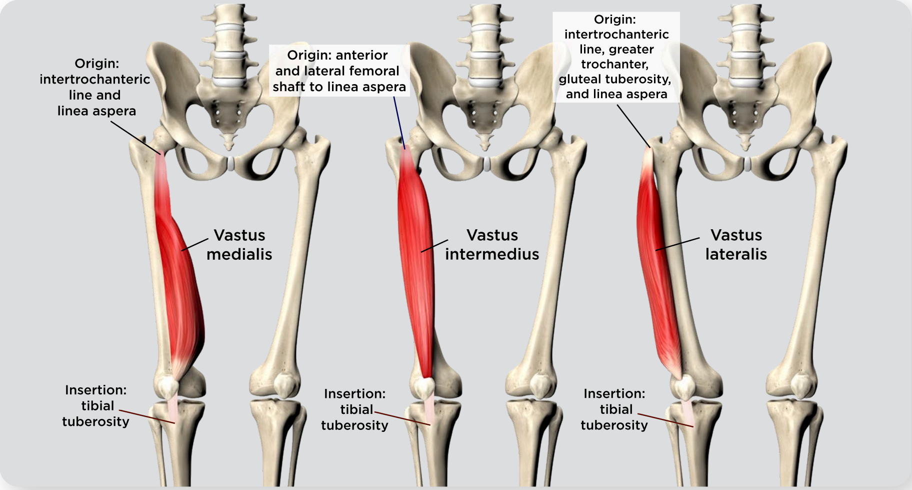
§ Many people refer to the quadriceps attachment to the tibia as the patellar tendon; however, tendons connect muscle to bone, while ligaments connect bone to bone.


Origin: intertrochanteric line and linea aspera
Vastus medialis
Insertion: tibial tuberosity
Origin: anterior and lateral femoral shaft to linea aspera
Vastus intermedius
Insertion: tibial tuberosity
Origin: intertrochanteric line, greater trochanter, gluteal tuberosity, and linea aspera
Vastus lateralis
Insertion: tibial tuberosity

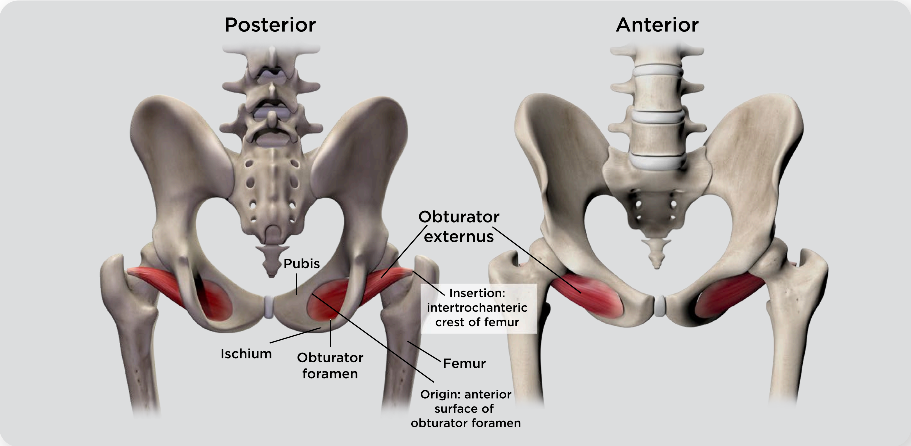
The final member of the quads, vastus intermedius, can't be seen from the surface because it is deep to rectus femoris. Vastus intermedius takes origin all along the anterior and lateral proximal two-thirds of the femur, including as far posteriorly as the linea aspera, and joins the other three members of the quadriceps femoris group to cross the anterior knee and attach to the tibial tuberosity.

All four muscles of the quadriceps group are innervated by the femoral nerve.

The Medial Thigh

The six muscles of the medial compartment of the thigh are the obturator externus, the pectineus, the gracilis, and the three members of the adductor group. Only one of the medial thigh muscles crosses the knee joint, but all cross the hip joint, and since most of those adduct the hip, some refer to the medial compartment as the adductor compartment. The obturator nerve dominates the supply of the muscles of the medial compartment of the thigh, but as with the anterior thigh, there are exceptions.

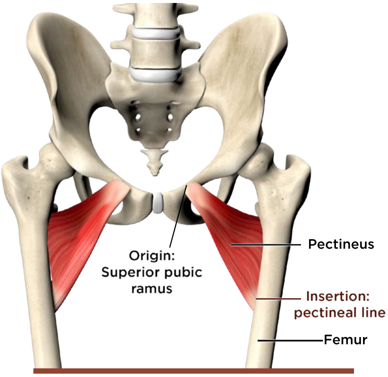
Obturator externus originates on the anterior surface of the obturator foramen, passes posteriorly between the pelvis and the neck of the femur, and inserts just inferior to the attachment of the inferior gemellus muscle.

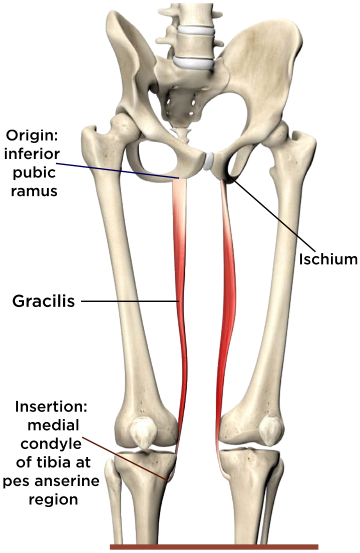

Posterior
Anterior
Obturator externus
Pubis
Insertion: intertrochanteric crest of femur
Ischium
Obturator foramen
Femur
Origin: anterior surface of obturator foramen

While it's not easily seen at the posterior aspect of the hip joint, the obturator externus also attaches among the series of lateral rotators deep in the gluteal region: piriformis, superior gemellus, obturator internus, inferior gemellus, and quadratus femoris. Specifically, it attaches just between the insertion of inferior gemellus and quadratus femoris. So, not only do the obturator externus and obturator internus flank either side of the obturator foramen of the pelvis, but both also pass posterior to the hip joint to insert along the deep aspect of the intertrochanteric crest.

Obturator externus also laterally rotates the thigh like the other members in that sequence. However, it is supplied by the obturator nerve off the lumbar plexus, while those other lateral rotators are supplied by nerves off the sacral plexus.

Next, the pectineus muscle originates on the superior ramus of the pubis and attaches to the pectineal line on the posteromedial femur. Because of its anterior origin on the pelvis and insertion on the medial femur, it flexes and adducts the thigh at the hip joint. The pectineus muscle may be supplied by the obturator nerve or the femoral nerve, or it may have branches from both.


Origin: Superior pubic ramus
Pectineus
Insertion: pectineal line
Femur


Origin: inferior pubic ramus
Ischium
Gracilis
Insertion: medial condyle of tibia at pes anserine region

The most medially placed muscle of the medial compartment is gracilis,¶ which is a long, narrow muscle that originates on the inferior ramus of the pubis, runs along the length of the medial thigh, and attaches to the pes anserine region near the medial condyle of the tibia. Like most other medial compartment muscles, gracilis adducts the hip and is supplied by the obturator nerve. But unlike any other muscle in the medial compartment, gracilis crosses the knee and, due to the position of its insertion, acts to aid flexion of the knee.

The three muscles of the adductor group are named for their relative sizes: adductor brevis, adductor longus, and adductor magnus.**

Typical of longus and brevis pairs, the adductor longus is more superficial. It sits just medial to pectineus and takes origin off the anterior aspect of the body of the pubic bone and inserts on the middle third of the linea aspera. Adductor brevis is deep to the longus; it originates off the inferior pubic ramus and inserts on the proximal third of the linea aspera. Both adduct the thigh but can also assist in flexion due to their more anterior origin and posterior insertion. Both adductor longus and adductor brevis are supplied by the obturator nerve.

The adductor magnus is said to have two parts, based on its different origins, insertions, actions, and even innervations. The adductor portion originates on the ischiopubic ramus and inserts on the linea aspera. Like its longus and brevis buddies, the adductor part of adductor magnus is also supplied by the obturator nerve and adducts and flexes the thigh. But the adductor magnus also has what's called its hamstring portion, which takes origin off the ischial tuberosity and inserts on the adductor tubercle projecting off the medial epicondyle of the femur. Like the hamstrings of the posterior thigh, the hamstring portion of the adductor magnus extends the thigh and is supplied by the sciatic nerve.

¶ *Gracile* means "slender."

** *Magnus* means "great" in Latin.

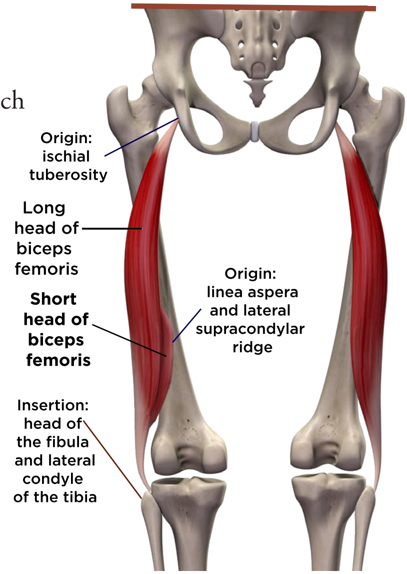
The Posterior Thigh

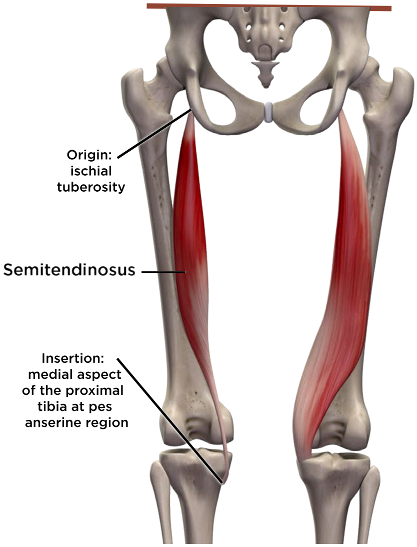
The remaining muscle compartment is the posterior thigh, which contains the three hamstrings: semitendinosus, semimembranosus, and biceps femoris. Each of the hamstrings take origin—all or in part—off the ischial tuberosity, but they differ in their insertions.

As its name implies, biceps femoris is a two-headed muscle: Its long head comes off the ischial tuberosity, but the short head originates from the linea aspera and lateral supracondylar ridge on the posterior femur. The two heads converge and insert in common on the head of the fibula and lateral condyle of the tibia. So only the long head of the biceps femoris extends the hip, whereas both heads cross the posterior knee to flex it.

The remaining two hamstrings, semitendinosus and semimembranosus, both take origin off the ischial tuberosity, the common hamstring origin, and together they travel to the medial aspect of the proximal tibia.

Where all three hamstrings cross the posterior hip, they extend it; all also cross the posterior knee and so act together to flex the knee. Biceps femoris is also said to assist with slight lateral rotation at the knee, while semimembranosus and semitendinosus assist with slight medial rotation of the knee.


Origin: ischial tuberosity
Long head of biceps femoris
Short head of biceps femoris
Insertion: head of the fibula and lateral condyle of the tibia
Origin: linea aspera and lateral supracondylar ridge


Origin: ischial tuberosity
Semitendinosus
Insertion: medial aspect of the proximal tibia at pes anserine region

Both the semimembranosus and semitendinosus are supplied by the tibial portion of the sciatic nerve. The long head of biceps femoris is supplied by the tibial portion of the sciatic nerve, but its short head is the only muscle in the body said to be supplied by the common fibular portion of the sciatic nerve before it branches into the superficial and deep fibular nerves. At the point where it supplies the hamstrings, the sciatic nerve still appears as a single entity—but even in the gluteal region, the sciatic nerve is already committed to its two main branches.

Semitendinosus is the third and final member of the pes anserine insertion group, which includes one member from each compartment: semitendinosus from the posterior thigh, gracilis from the medial compartment, and sartorius anteriorly. All three muscles come together and attach at the proximal medial tibia, and because the insertions are slightly posterior to the hinge joint of the knee, all aid in knee flexion.

Reading

Biel, *Trail Guide to the Body*, ch. 6, "Pelvis & Thigh."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 9, "Muscles of the Hip and Thigh."

Delavier, *Strength Training Anatomy*, ch. 5, "Legs."

Dimon, *Anatomy in Action*, ch. 11, "The Leg Spirals."

Jarmey, *The Concise Book of Muscles*, ch. 9, "Muscles of the Hip and Thigh."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 8, "Muscles of the Hip and Thigh."

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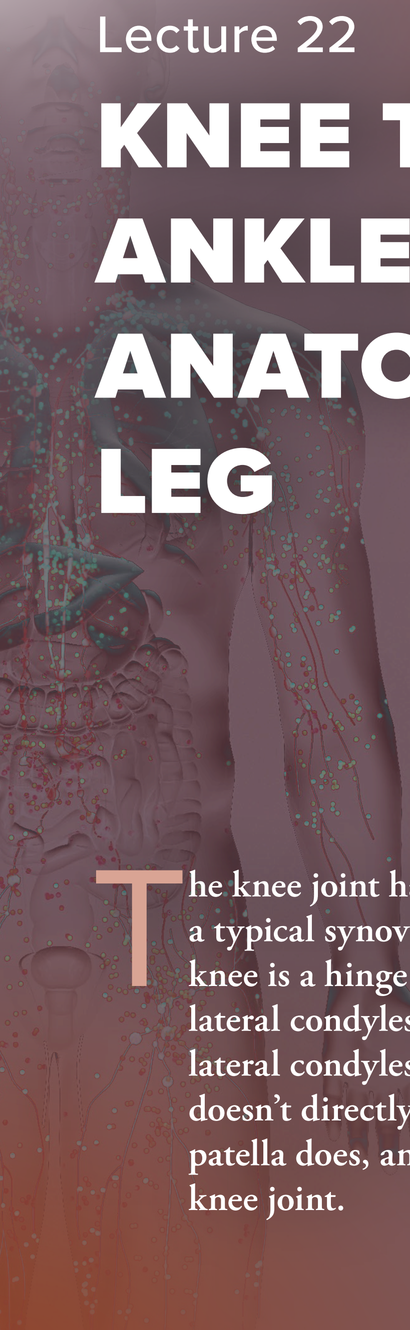
Lecture 22

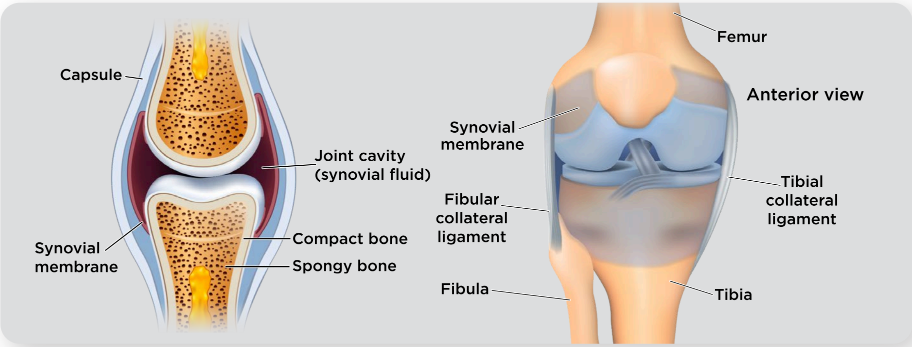
KNEE TO ANKLE: THE ANATOMICAL LEG



The knee joint has all the bells and whistles of a typical synovial joint—and then some. The knee is a hinge joint between the medial and lateral condyles of the femur and the medial and lateral condyles of the tibia. While the fibula doesn't directly articulate with the femur, the patella does, and both are crucial elements of the knee joint.

The Knee

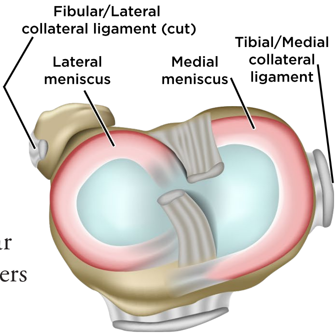
Since the knee is a hinge joint, collateral ligaments are found on either side of it. The tibial collateral ligament, referred to as the medial collateral ligament (MCL), is a relatively wide and flat ligament that connects the medial epicondyle of the femur to the medial condyle and proximal shaft of the tibia. It's considered an intrinsic ligament because it blends with the knee joint's capsule—a connective tissue sleeve that covers many synovial joints.


Capsule
Joint cavity (synovial fluid)
Synovial membrane
Compact bone
Spongy bone
Femur
Anterior view
Synovial membrane
Fibular collateral ligament
Tibial collateral ligament
Fibula
Tibia

The fibular collateral ligament, commonly known as the lateral collateral ligament (LCL), connects the lateral epicondyle of the femur to the head of the fibula. It's much more cord-like and more mobile than the MCL and is an extrinsic ligament, given that it is not connected to the joint capsule.

The so-called tibial plateau is not exactly flat, since between the medial and lateral condyles of the tibia is a projection known as the intercondylar eminence. On either side of this intercondylar eminence sit the menisci of the knee. These fibrocartilaginous pads are articular discs.

The medial meniscus is more C-shaped when seen from above, while the lateral meniscus is more O-shaped. The menisci sit atop the articular cartilage of the tibia and are connected to the tibia at their edges by small attachments known as coronary ligaments. Each meniscus functions to slightly deepen its articular surface on the tibia; the menisci act like cupholders


Fibular/Lateral collateral ligament (cut)
Lateral meniscus
Medial meniscus
Tibial/Medial collateral ligament

for the rounded condyles of the femur, helping them sit on the much flatter tibial condyles. The menisci also cushion the femur on the tibia and so are protective as we walk, run, and jump.

Between the medial and lateral condyles of the tibia, the cruciate* ligaments attach to the tibia's intercondylar eminence, which consists of two small peaks: one for attachment of the anterior cruciate ligament (ACL) and the other for the posterior cruciate ligament (PCL).

The modifiers *anterior* and *posterior* are best understood relative to the attachments on the tibia. In other words, the *anterior* cruciate ligament attaches to the *anterior* part of the intercondylar eminence on the tibia and passes posteriorly to attach to the posteromedial part of the lateral femoral condyle. The ACL prevents the femur from moving posteriorly on the tibia. The *posterior* cruciate ligament attaches on the *posterior* part of the tibia's intercondylar eminence and passes anteriorly to attach to the anterolateral side of the femur's medial condyle. The PCL prevents the femur from moving anteriorly on the tibia.

Since they are within the capsule of the knee joint, the cruciate ligaments are said to be intracapsular, but they are also said to be extra-synovial, meaning that the cruciate ligaments are outside the thin, transparent synovial membrane that lines the joint.

A few other smaller knee joint ligaments called the arcuate and oblique popliteal ligaments help strengthen the posterior part of the joint. However, the anterior stability for the knee joint is largely derived from the tendon of the quadriceps femoris muscles and the patellar ligament that the quadriceps tendon becomes. In fact, the sleevelike capsule is deficient anteriorly and is essentially replaced by the tendon of the quads and patellar ligament. Additional lateral stabilization is provided by the iliotibial tract and the vastus lateralis muscle, while vastus medialis helps with medial stability.

The knee also has numerous bursae, which are friction-reducing pockets of synovial membrane between adjacent structures at a joint.

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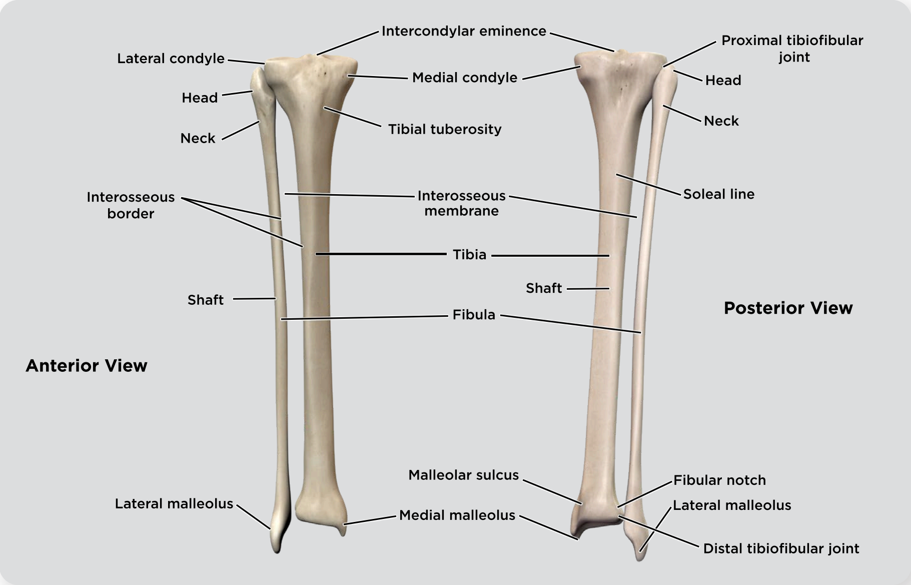
* *Cruciate* means "cross-like," since these two ligaments form an anterior-to-posterior *X* within the knee joint.

The Tibia and the Fibula

You've learned about much of the proximal tibia, including its condyles, intercondylar eminence, and tibial tuberosity, where the patellar ligament attaches. On the proximal tibia's posterior aspect is a landmark called the soleal line. Continuing distally along the shaft of the bone, the tibia is more triangular than round in cross section and has a raised ridge along its anterior border. The tibia is so close to the surface that you can easily feel it as the shin on yourself.

At its distal end, the tibia expands medially into a prominence called the medial malleolus, and on the lateral aspect of the distal tibia, there's a fibular notch to receive the adjacent fibula. The result of the juxtaposition of the tibia and fibula creates both a proximal tibiofibular joint just posterolateral to the knee and a distal tibiofibular joint at the ankle.

As for the fibula, the fibular head, located proximally, is followed by a constricted neck. The thin shaft of the fibula travels distally to terminate in a prominence known as the lateral malleolus. Between the tibia and fibula runs the interosseous membrane that not only helps connect the two leg bones but also aids in compartmentalizing the leg.

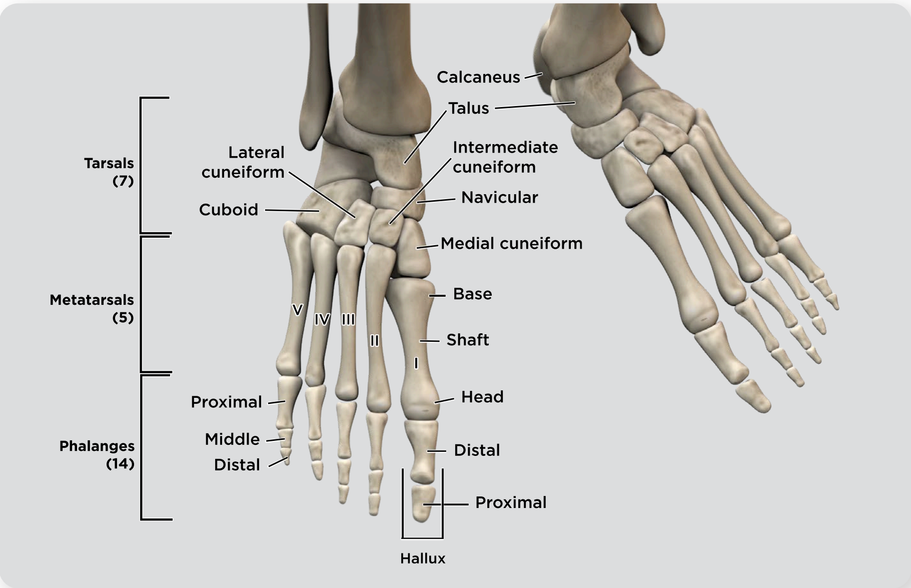

Intercondylar eminence
Lateral condyle
Proximal tibiofibular joint
Medial condyle
Head
Head
Neck
Neck
Tibial tuberosity
Interosseous border
Interosseous membrane
Soleal line
Tibia
Shaft
Shaft
Fibula
Posterior View
Anterior View
Malleolar sulcus
Fibular notch
Lateral malleolus
Lateral malleolus
Medial malleolus
Distal tibiofibular joint

The leg can be referred to as the crural or sural region, and like the fascia lata of the thigh, the leg muscles are surrounded by a dense covering of fascia called the crural fascia. Two deep extensions—called the anterior crural intermuscular septum and posterior crural intermuscular septum—connect the outer sleeve of fascia down to the fibula. Along with the interosseous membrane, these help divide the leg into its three subdivisions: the anterior, lateral, and posterior compartments. A third major plane of connective tissue, the transverse crural intramuscular septum, further separates the posterior compartment into a group of superficial muscles and a group of deep muscles.

To generalize compartment functions, the muscles in the anterior leg all cross the anterior ankle to cause dorsiflexion of the ankle, such as walking on your heels. Some cause extension of the toes, such as pointing them toward the ceiling. Likewise, muscles in the posterior compartment can plantar flex the ankle, such as walking on your toes, and some flex the toes, such as curling them toward the sole of your foot. Several posterior compartment muscles also cross the posterior knee and so assist in flexing the knee. Muscles in the lateral compartment of the leg evert the foot, while some tendons of muscles in both the anterior and posterior compartments cross the medial ankle to invert the foot.

The Bones of the Foot

There are seven bones of the ankle region that are collectively referred to as the tarsals. The talus is the tarsal that articulates at the ankle with the inferior articular surface of the tibia, as well as both the medial malleolus of the tibia and the lateral malleolus of the fibula. The talus sits proximal to, or atop, the calcaneus, which is the tarsal that forms the heel. Medially in the foot, the navicular bone articulates with the anterior part of the talus, and distally the navicular articulates with three small wedge-shaped bones called the cuneiforms. These can be called the first, second, and third cuneiforms or, alternatively, the medial, intermediate, and lateral cuneiforms. But the lateral cuneiform isn't the most lateral of the tarsals; the cuboid bone sits laterally and articulates with the anterior part of the calcaneus.


Tarsals (7)
Metatarsals (5)
Phalanges (14)
Lateral cuneiform
Cuboid
Calcaneus
Talus
Intermediate cuneiform
Navicular
Medial cuneiform
Base
Shaft
Head
V
IV
III
II
I
Proximal
Middle
Distal
Distal
Proximal
Hallux

Distal to that final row of four tarsals are the five metatarsals of the sole of the foot—so the relationship is not a one-to-one ratio. Each metatarsal has a proximal base, a shaft, and a distal head, as with the metacarpals of the palm. The first metatarsal is the most medially located, belonging to the big toe, and like in the hand, metatarsals are designated with Roman numerals I through V—with I given to hallux, which is the name for the big toe or great toe, and V for the metatarsal of the little toe.

As in the thumb, the big toe has two phalanges—a proximal and a distal—and the other four toes have three phalanges: proximal, middle, and distal. Each phalanx is said to have a base, shaft, and head, though in the smaller toes, the middle phalanx is nothing more than a small rectangular bone.

Movements Caused by Muscles in the Leg

Dorsiflexion and plantar flexion occur at the true ankle joint between the talus and the tibia and fibula, but inversion and eversion occur within the foot itself.

Each muscle compartment of the leg has a unique nerve supply. The sciatic nerve is composed of a tibial portion and a common fibular portion, and these two nerves typically diverge from one another in the popliteal region behind the knee, terminating the sciatic nerve. And from there, the tibial nerve travels distally and stays in the posterior compartment to supply all leg muscles posterior to the interosseous membrane.

The common fibular branch of the sciatic heads laterally in the popliteal area for a short distance and near the head of the fibula divides into a superficial fibular nerve that supplies the two muscles of the lateral leg and a deep fibular nerve that passes deeply forward to supply the muscles in the anterior leg. This is the reason that the sciatic nerve off the sacral plexus, by virtue of its branches, supplies all muscles below the knee.

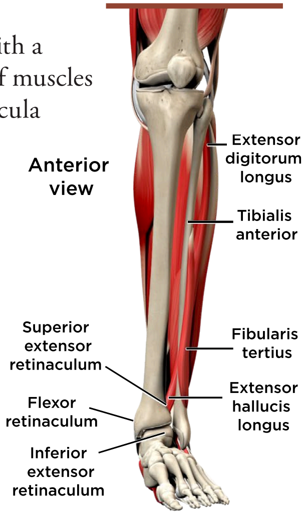
The Anterior Leg

At the ankle, the crural fascia thickens anteriorly into transverse bands known as the superior and inferior extensor retinacula, which keep tendons of the anterior leg aligned with the ankle and prevent the bowstringing that would otherwise happen during dorsiflexion. It's as if we're wearing a band around the ankle, as is seen at the wrist.

The superior extensor retinaculum is continuous with a flexor retinaculum that sits superficial to tendons of muscles in the posterior leg. There are also thickened retinacula that bind down the lateral compartment's muscle tendons and help secure them to facilitate the actions of their muscles.

There are four muscles in the anterior leg: tibialis anterior, extensor hallucis longus, extensor digitorum longus, and fibularis or peroneus tertius.†

When you feel along your shin, the muscle mass immediately lateral to the sharp crest of the tibia is tibialis anterior. It takes origin from the proximal half of the tibia's lateral surface as well



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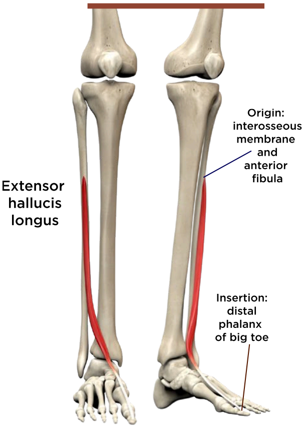
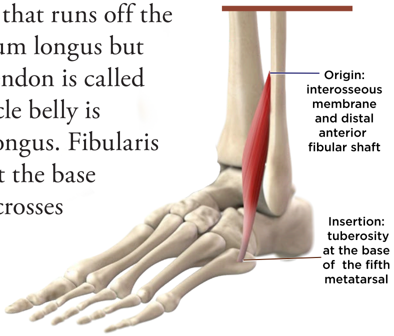
† In anatomy, the word *peroneus* is gradually being replaced by *fibularis*.

as the interosseous membrane. The large tendon of tibialis anterior can be seen passing across the anterior and medial aspect of the ankle to insert on the medial cuneiform and the base of the first metatarsal. Because it crosses the anterior ankle, tibialis anterior dorsiflexes. And because it crosses the medial aspect of the ankle to insert on the foot, it inverts.


Extensor hallucis longus
Origin: interosseous membrane and anterior fibula
Insertion: distal phalanx of big toe

The extensor hallucis longus muscle originates off the interosseous membrane but also off the anterior fibula. As its name implies, extensor hallucis longus inserts on and extends the great toe, and as a longus muscle, it goes the long way and inserts on the distal phalanx. But its tendon crosses the anteromedial aspect of the ankle, so it also dorsiflexes and inverts the foot. The extensor digitorum longus muscle takes origin off the interosseous membrane, too, but additionally off the lateral condyle of the tibia and the anterior fibula. It inserts on the middle and distal phalanges of the four lateral toes. Extensor digitorum longus's name reveals its function in toe extension, but because its tendon crosses the anterior ankle and then fans out laterally toward the smaller toes, extensor digitorum longus can also assist in ankle dorsiflexion and eversion of the foot.


Origin: interosseous membrane and distal anterior fibular shaft
Insertion: tuberosity at the base of the fifth metatarsal

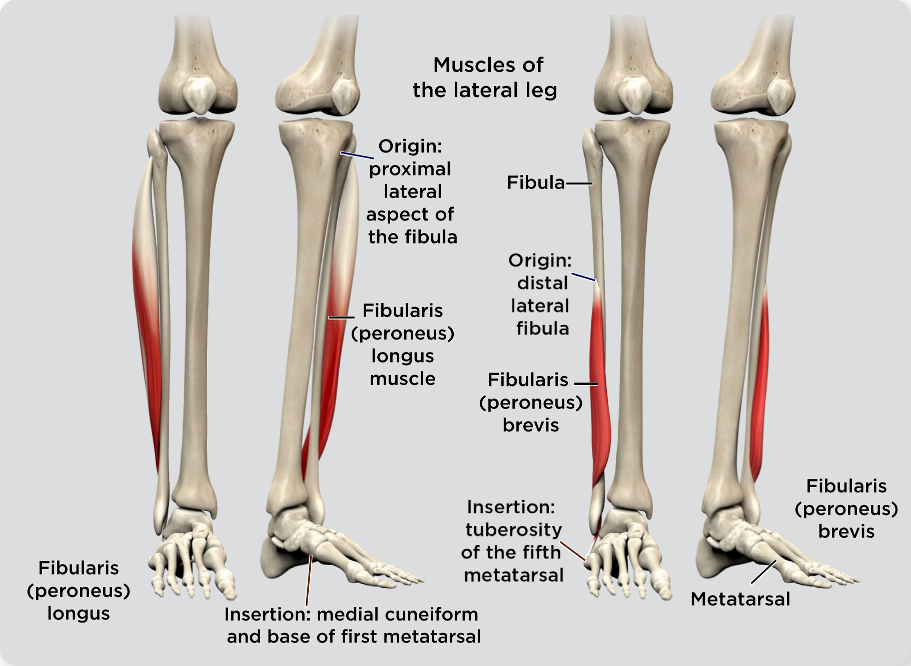
In most people, there's an additional tendon that runs off the distal and lateral portion of extensor digitorum longus but doesn't attach to a toe. When present, this tendon is called fibularis or peroneus tertius, though its muscle belly is indistinguishable from extensor digitorum longus. Fibularis tertius inserts on the tuberosity or tubercle at the base of the fifth metatarsal. Because this tendon crosses the anterior and lateral aspect of the ankle, it dorsiflexes and everts the foot. *Tertius* means "third," and you are about to meet two other fibularis buddies in the lateral leg.

All four muscles of the anterior leg are supplied by the deep fibular nerve, off the common fibular branch of the sciatic nerve.

The Lateral Leg

The two muscles in the slender lateral leg compartment are fibularis longus and fibularis brevis, also known as peroneus longus and brevis. The fibularis longus originates on the proximal lateral aspect of the fibula and has a much longer tendon, as its name implies. That tendon sits superficial to the belly of fibularis brevis, which originates more distally on the lateral fibula.

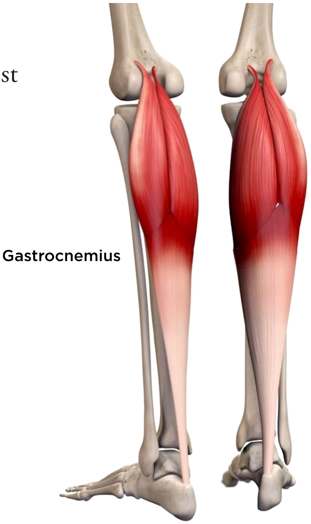
Both muscles send their tendons across the lateral ankle and function to evert the foot. But fibularis brevis inserts on the tuberosity of the fifth metatarsal with its tertius companion, while the fibularis longus goes the long way, passing under the sole of the foot from lateral to medial and inserting on the inferior aspect of the base of the first metatarsal—the one on the big toe side. Not only does this facilitate eversion of the foot, but the tendon of fibularis longus helps support the sole of the foot. Both muscles of the lateral compartment are supplied by the superficial fibular nerve, a branch of the common fibular off the sciatic nerve.


Muscles of the lateral leg
Origin: proximal lateral aspect of the fibula
Fibularis (peroneus) longus muscle
Fibularis (peroneus) longus
Insertion: medial cuneiform and base of first metatarsal
Fibula
Origin: distal lateral fibula
Fibularis (peroneus) brevis
Insertion: tuberosity of the fifth metatarsal
Fibularis (peroneus) brevis
Metatarsal

The Posterior Leg

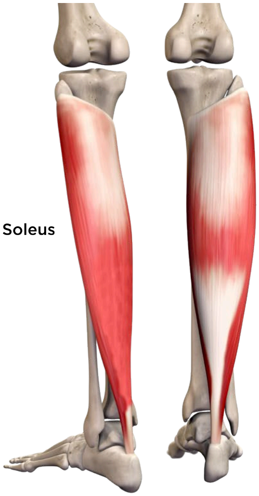
The posterior compartment of the leg contains six or seven muscles, depending on whether the person has a plantaris muscle. So just like in the forearm, there's a variable muscle in the leg.

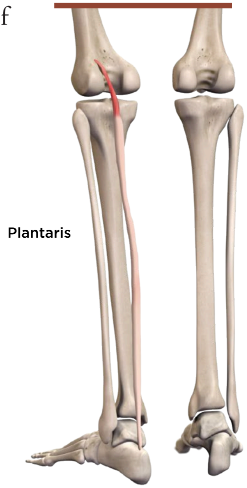
The most obvious muscle of the posterior leg is the gastrocnemius, which makes up the prominence most people call the calf. Gastrocnemius is a two-headed muscle that crosses both the knee and the ankle; its lateral and medial heads originate off the respective posterior aspects of the femoral condyles and popliteal surface of the femur. The heads combine to insert on the posterior aspect of the calcaneus by the calcaneal tendon, which most people call the Achilles tendon. Because it crosses the posterior knee, the gastrocnemius assists in knee flexion—along with the hamstrings and other muscles in the thigh—and because it crosses the posterior ankle, it mainly acts in plantar flexion.



Deep to the gastrocnemius is the soleus muscle, which takes origin off the soleal line of the tibia and the posterior fibula and inserts along with the gastrocnemius by the calcaneal tendon. Because soleus is a wider and slightly more distal muscle, its belly can typically be seen on either side of gastrocnemius. Soleus doesn't cross the knee but plantar flexes the ankle with the gastrocnemius.

Within the calcaneal tendon, you really can't differentiate gastrocnemius and soleus—the tendons fuse. Though both muscles aid in running and jumping, the soleus is more of an endurance muscle and also aids balance when on one foot. Soleus is the prime mover in plantar flexion when the knee is bent, since gastrocnemius is slack in that position.





The last muscle that might be in the superficial region of the posterior leg is the plantaris. It is a variable muscle that has a tiny belly that takes origin from the femur's lateral supracondylar ridge. The tendon of plantaris sometimes fuses with the calcaneal tendon but other times stays separate to attach to the calcaneus.

Most people have a plantaris, and when present, it is said to weakly flex the knee and weakly plantar flex the ankle.

These two or three muscles in the superficial posterior leg are separated from the four deeper muscles in the posterior leg by the transverse intermuscular septum. The deep posterior leg includes tibialis posterior, flexor hallucis longus, and flexor digitorum longus, with adjectives that mirror three of the four muscles of the anterior leg (tibialis anterior, extensors hallucis longus, and extensors digitorum longus). The fourth muscle of the deep posterior leg is popliteus, which crosses only the knee, originating off the lateral femoral condyle and inserting on the proximal posterior tibia. It is said to unlock the knee joint by slight rotation at the knee joint.

An estimated 80% or more of people, depending on population, have a plantaris muscle.

The three deep posterior muscles that mirror their anterior counterparts have an unusual relationship in the posterior leg. The belly of tibialis posterior is intermediate, while flexor hallucis longus is lateral, on the little toe side, and flexor digitorum longus is medial, on the big toe side. When you think of their functions, that is odd—but the tendons of flexor hallucis longus and flexor digitorum longus make an *X* at the medial ankle and then approach their respective insertions. Tibialis posterior originates on the posterior tibia, posterior fibula, and interosseous membrane; it passes posteromedially and inserts on most of the tarsals and metatarsals. Tibialis posterior functions to plantar flex and invert the foot.

Flexor hallucis longus takes origin from the posterior fibula and interosseous membrane and inserts on the plantar surface of the distal phalanx of the big toe. Flexor digitorum longus originates off the posterior tibia and inserts on the distal phalanges of the other toes. Besides flexing their respective toes, since both flexor hallucis longus and flexor digitorum longus cross the posteromedial ankle, they assist in plantar flexion and inversion of the foot. They are also important to the arches of the foot and for attachments of some muscles in the sole of the foot.

All muscles of the posterior leg, whether superficial or deep, are supplied by the tibial branch of the sciatic nerve.

Reading

Biel, *Trail Guide to the Body*, ch. 7, "Leg & Foot."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 10, "Muscles of the Lower Leg and Foot."

Delavier, *Strength Training Anatomy*, ch. 5, "Legs."

Jarmey, *The Concise Book of Muscles*, ch. 10, "Muscles of the Leg and Foot."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 9, "Muscles of the Leg and Foot."

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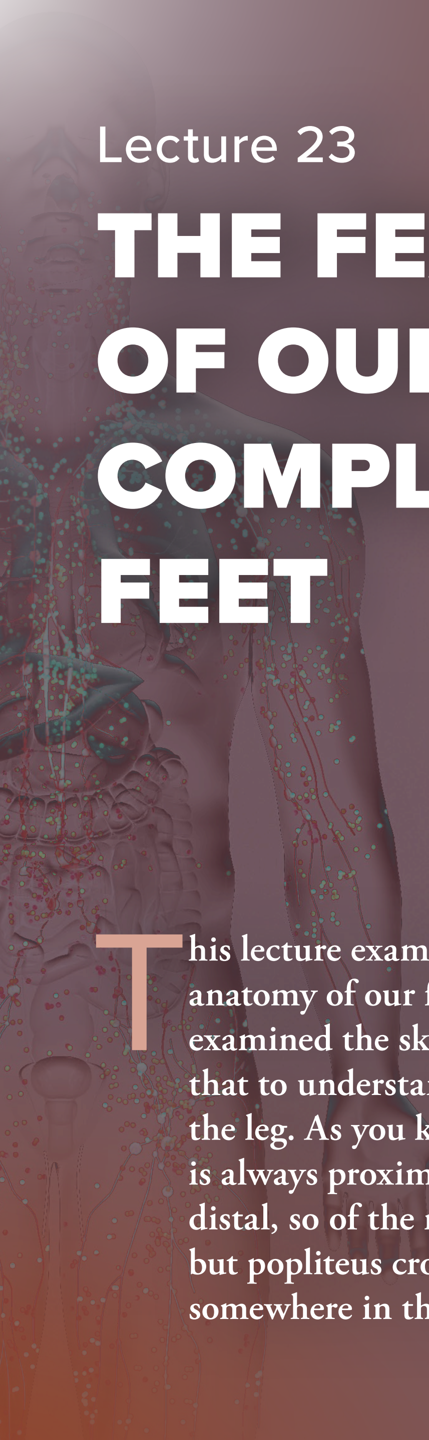

Lecture 23

THE FEATURES OF OUR COMPLICATED FEET

This lecture examines the musculoskeletal anatomy of our feet. The previous lecture examined the skeleton of the feet since you need that to understand the insertions of muscles in the leg. As you know, in the limbs, the origin is always proximal and the insertion always distal, so of the many muscles in the leg, all but popliteus cross the ankle joint and attach somewhere in the foot.

The Feet and Ankle

In each foot, there are seven tarsals, five metatarsals, and 14 phalanges, and the tarsals in particular are linked together like pieces in a jigsaw puzzle. Just imagine how many ligaments are necessary to hold that complex together and support the weight of our entire body, plus anything we're carrying.

These ligaments generally come in dorsal varieties on the top of the foot and plantar versions on the sole of the foot. As a bonus, they are usually named sensibly enough that you can figure out which bones they connect.

The ligaments at the ankle between the talus and the tibia and fibula of the crural region, or leg, are called the talocrural joint.

Medially, at the hinge joint of the ankle, is a set of ligaments collectively referred to as the deltoid ligament. This is because they fan out like a triangle—like the Greek letter delta—from the medial malleolus of the tibia and attach to various tarsals. This deltoid ligament can be broken down into four bands: an anterior tibiotalar ligament, a posterior tibiotalar ligament, a tibionavicular ligament, and a tibiocalcaneal ligament.* The anterior tibiotalar is deep to the tibionavicular, so can be difficult to see in images, depending on the view. This deltoid group is very strong and resists over-eversion of the foot.

On the lateral aspect of the ankle joint, there's a series of three bands sometimes referred to as the lateral collateral ligament. There's an anterior talofibular ligament and a posterior talofibular ligament, and between them is a calcaneofibular ligament.†

These lateral ligaments resist over-inversion of the foot and are not nearly as strong as the ligaments of the medial ankle. The ankle joint has a thin anterior and posterior capsule, so its main reinforcements are on the sides, which is typical of a hinge joint.

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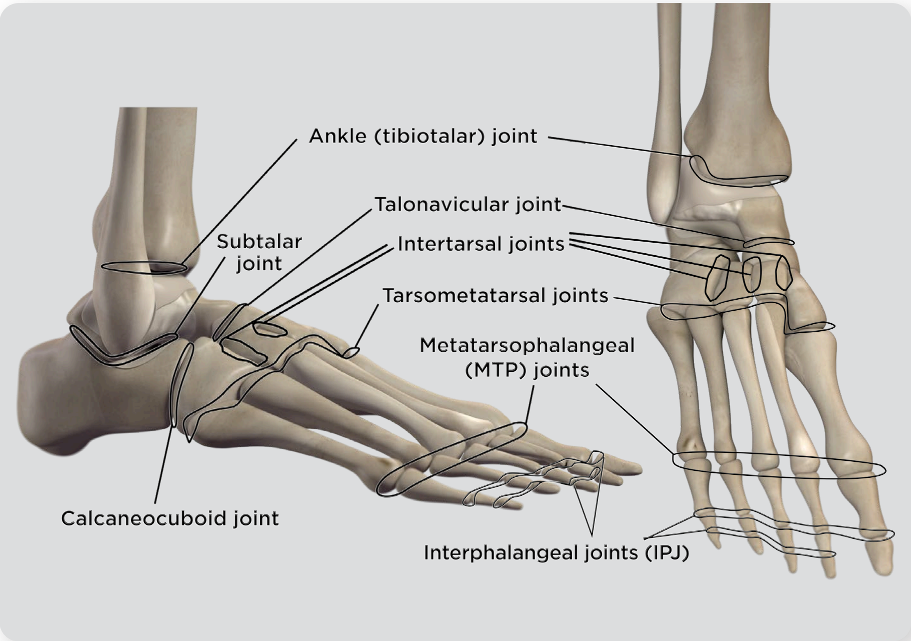
* Notice that in each of these, *tibio-* is like the first name of the ligament, and the tarsal it connects to is like its last name.

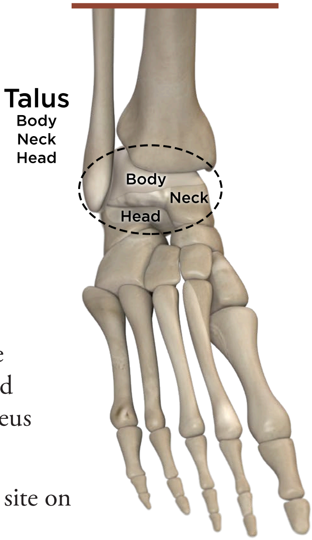
† Notice that in a pattern similar to the naming of the bands of the deltoid ligament, these lateral ligaments all have the tarsal to which they attach as their "first name" but have the fibula as their "last name."

Within the foot itself, there are intertarsal joints, which are gliding joints between the various tarsals, as well as tarsometatarsal joints that link the distal row of tarsals to the five metatarsals. These are also gliding joints that allow planes of movement, such as during inversion and eversion of the foot.

Moving distally, there are metatarsophalangeal (MTP) joints between the heads of the five metatarsals and their proximal phalanges. These are condyloid joints in which the heads of the metatarsals are rounded and abut concave surfaces on the proximal phalanges. Because condyloid or ellipsoidal joints allow more movement than simple hinge joints, at the MTP joints there is not only flexion and extension but abduction, adduction, and even a bit of circumduction.

Within each toe are interphalangeal joints (IPJs) with collateral ligaments on either side. There's one IPJ in the big toe between its proximal and distal phalanx and two IPJs in each of the smaller toes, which contain three phalanges each.


Ankle (tibiotalar) joint
Subtalar joint
Talonavicular joint
Intertarsal joints
Tarsometatarsal joints
Metatarsophalangeal (MTP) joints
Calcaneocuboid joint
Interphalangeal joints (IPJ)



The talus is said to have a head, neck, and cube-shaped body. While the body articulates with the tibia and fibula, the head faces anteriorly—or, better said, distally. Some references indicate it as forming basically a ball-and-socket joint with the concave surface of the boat-shaped navicular bone. Besides its role in ankle movements, the talus functions to transmit the standing weight of the body from the tibia to the other bones in the foot.

The calcaneus is the largest foot bone and forms the heel. Medially on the calcaneus is a small shelf called the sustentaculum tali, because it widens the calcaneus just inferior to its articulation with the talus.

The calcaneal tuberosity is a prominent attachment site on the inferior and posterior surface of the calcaneus. But the Achilles, or calcaneal, tendon attaches to the superior and posterior aspect of the calcaneus—that's the insertion of the gastrocnemius, soleus, and plantaris of the posterior leg.

Some people, particularly those without the use of their upper limbs, learn to use their feet to aid with daily activities or hobbies. In these cases, they don't alter their bony anatomy but rather train their muscles and stretch their ligaments for these tasks.

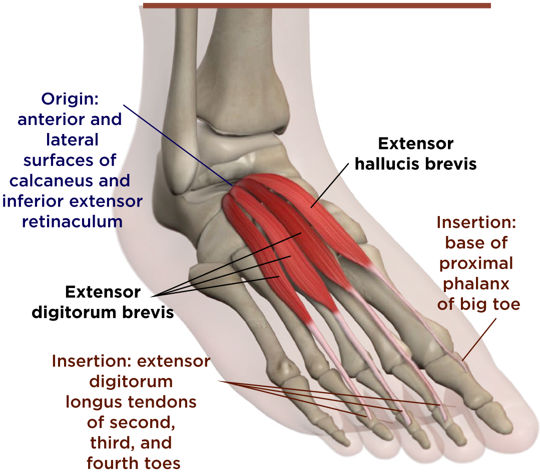
Muscles of the Feet

There are a dozen intrinsic muscles within each foot—more than are in each hand. Ten of those muscles are in the plantar foot, and they are considered in four layers.

The two on the dorsum of the foot are the extensor hallucis brevis and extensor digitorum brevis. There aren't any intrinsic muscles on the dorsum of the hand, but we do have a pair on the top of the foot, and each has a longus buddy in the anterior leg.

Both extensor hallucis brevis and extensor digitorum brevis take origin off the anterior and lateral surfaces of the calcaneus as well as the inferior extensor retinaculum on the dorsum of the foot.‡

Extensor hallucis brevis inserts on the base of the big toe's proximal phalanx, while extensor digitorum brevis inserts on the second, third, and fourth toes—actually on the lateral sides of their extensor digitorum longus tendons, which have small extensor hoods like those in the dorsal hand. So, extensor hallucis brevis extends the big toe at its MTP joint, while extensor digitorum brevis extends other toes, except for the little toe, at both their MTPs and IPJs.


Origin: anterior and lateral surfaces of calcaneus and inferior extensor retinaculum
Extensor hallucis brevis
Insertion: base of proximal phalanx of big toe
Extensor digitorum brevis
Insertion: extensor digitorum longus tendons of second, third, and fourth toes

These brevis muscle bellies are deep to the tendons of extensor hallucis longus and extensor digitorum longus that run distally along the dorsum of the foot.

The deep fibular nerve supplies muscles of the anterior leg and continues distally to supply the extensor hallucis brevis and extensor digitorum brevis.

Moving to the plantar surface, the skin on the sole of the foot is thick and protective, like the skin of the palmar hand. In addition, this plantar skin is firmly attached to deeper structures, unlike on the dorsum of the foot, which has loose skin like the back of the hand. If this plantar skin wasn't anchored to the deeper structures, the skin would slide around like a loose sock. Deep to this thick skin is a triangle of connective tissue, the plantar aponeurosis, more commonly known as the plantar fascia. Its apex attaches to the calcaneal tuberosity, and its wide end attaches to the heads of the metatarsals.

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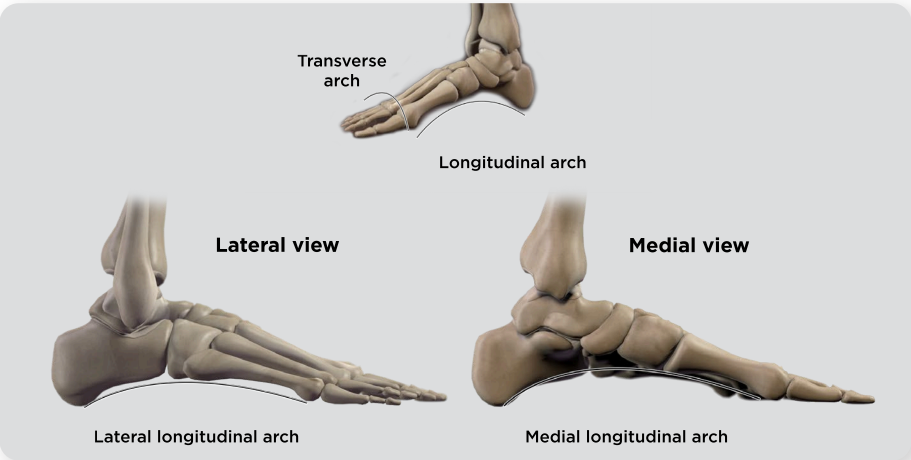
‡ Due to this common origin, some references don't separate the two muscles and simply collectively call them extensor digitorum brevis.

The plantar aponeurosis not only protects deeper nerves, vessels, and muscles but also helps maintain the arches in the foot. There are a pair of longitudinal arches that pass between the heel and toes. The medial arch is higher at the instep, as we know from the pads in our shoes, while the lateral longitudinal arch is lower. There's also a counterpart transverse arch running medially to laterally across the plantar foot—it's also higher at the instep and lower laterally. The many ligaments on the sole of the foot help maintain those arches, as do several plantar muscles.

In the relatively common condition called plantar fasciitis, the attachment of the aponeurosis to the calcaneus becomes inflamed, causing significant heel pain.

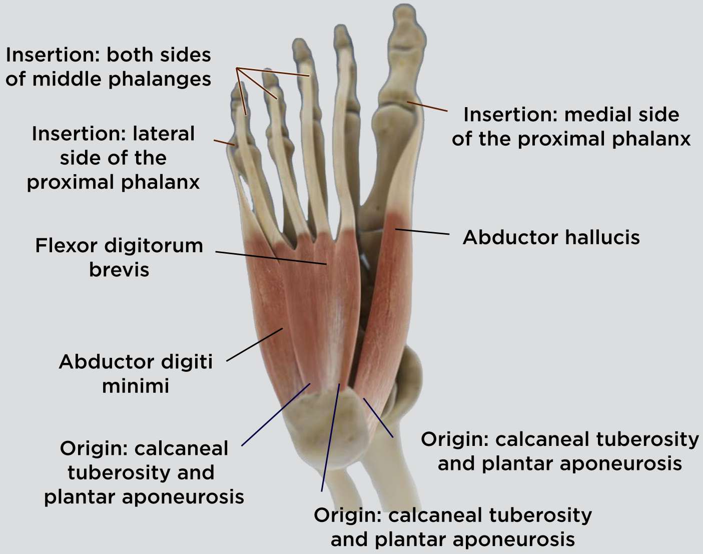
There are some tricks to learning the many muscles in the plantar foot. One helpful thing is to consider them in four layers. There are three muscles in the first layer, two muscles and two tendons in the second layer, three muscles in the third layer, and, again, two muscles and two tendons in the fourth layer. In other words, the first and third layers—the odd-numbered layers—each have three muscles in them, and three is an odd number. The second and fourth layers, the even-numbered layers, have an even number of muscles in them: two muscles and an equal number of two tendons.



As for the innervations of the plantar muscles, the tibial nerve, one of the two terminal branches of the sciatic nerve, supplies the muscles of the posterior leg. Then, at the medial ankle, really at the instep of the foot, the tibial nerve divides into a medial plantar nerve and a lateral plantar nerve. One, the other, or both of these supplies each of the muscles on the sole of the foot.

In the first layer, the three muscles from medial to lateral are the abductor hallucis, flexor digitorum brevis, and abductor digiti minimi for the little toe. There is no abductor digiti maximi; the counterpart for the little toe is hallux, the big toe. Most people cannot independently abduct their big toe, nor can most abduct their little toe on its own, though some people can. But when you think of abduction, you should picture fanning the foot out, like stretching to spread your toes apart.

Abductor hallucis takes origin from the calcaneal tuberosity and plantar aponeurosis and inserts on the medial side of the proximal phalanx of the big toe. Not only does it abduct the great toe, but abductor hallucis also slightly flexes the big toe at its MTP joint and helps maintain the medial side of the longitudinal arch of the foot.


Insertion: both sides of middle phalanges
Insertion: lateral side of the proximal phalanx
Flexor digitorum brevis
Abductor digiti minimi
Origin: calcaneal tuberosity and plantar aponeurosis
Insertion: medial side of the proximal phalanx
Abductor hallucis
Origin: calcaneal tuberosity and plantar aponeurosis
Origin: calcaneal tuberosity and plantar aponeurosis

Abductor digiti minimi also takes origin from the calcaneal tuberosity and plantar aponeurosis and inserts on the lateral side of the proximal phalanx of the little toe. In addition to abduction, abductor digiti minimi helps flex the little toe and maintains the lateral side of the longitudinal arch.

The third muscle, flexor digitorum brevis, also originates off the calcaneal tuberosity and from the plantar aponeurosis directly superficial to it. In lab, it can be difficult to remove the plantar aponeurosis from the surface of flexor digitorum brevis without damaging the muscle. The insertion is on the two sides of each middle phalanx of the second through fifth toes.

Similar to what is seen in the hand, these brevis tendons split like a fork to allow the tendons of flexor digitorum longus—which are deep to the belly of flexor digitorum brevis—to pass through that fork and insert on the distal phalanges of the smaller toes. So, when you curl your toes, the flexor digitorum brevis muscle is flexing the proximal IPJs, while the flexor digitorum longus is flexing the distal IPJs as well as the proximal IPJs, since it crosses both. Both muscles also help flex the MTP joints, but all this applies to only the second through fifth toes.

Regarding the innervations in this first layer of the plantar foot, the medial plantar nerve supplies abductor hallucis on the big toe side, while the lateral plantar nerve supplies abductor digiti minimi on the little toe side. Flexor digitorum brevis is between the two abductors and is supplied by the medial plantar nerve.

The two abductors are placed on the edges of the sole of the foot; they each insert on the outside aspect of their respective toes. They form the fleshy mass on either edge of the foot—felt especially more toward the heel end of your foot.

In the second layer, going deeper into the plantar foot, one tendon is the tendon of flexor hallucis longus, and the other consists of the group of tendons from the flexor digitorum longus. While the tendon of flexor hallucis longus is just passing through this layer, the tendons of flexor digitorum longus serve as attachments for both of the muscles in this second layer.

Like in the palm of the hand, a set of four lumbrical muscles weaves between and takes origin off the tendons of flexor digitorum longus. The lumbricals insert on the dorsal sides of the proximal phalanges of the four smaller toes—really into their tiny extensor hoods from the dorsal side. By this pathway, as the lumbricals did in the hand, the muscles cross the plantar side of the MTP joints of the four smaller toes and so flex the MTPs but then pass to the dorsum, where they weakly act to extend the IPJs.

As in the hand, these lumbricals have dual innervation: The one to the second toe is supplied by the medial plantar nerve, while the others are supplied by the lateral plantar nerve.

The other muscle in the second layer of the plantar foot is quadratus plantae, a quadrangular-shaped muscle of the sole of the foot. It's really a two-headed muscle that takes part of its origin off the medial side of the calcaneus and originates partly off the inferolateral calcaneus. Both heads converge and insert on the lateral edge of the tendon of flexor digitorum longus. Quadratus plantae functions to adjust the pull of the flexor digitorum longus tendons to help them flex the toes. Quadratus plantae is lateral to its tendon of insertion, and that helps you remember that it is innervated by the lateral plantar nerve.

The third layer of muscles, like the first, contains three muscles, and two of those three mirror the pattern seen in the first layer. In that first layer is an abductor of the big toe and an abductor of the little toe; in this third layer, there's a flexor of the big toe and a flexor of the little toe.

Flexor hallucis brevis is a two-bellied muscle that originates off the cuboid and lateral cuneiform. Its medial and lateral heads insert, respectively, on the medial and lateral sides of the base of the proximal phalanx of the big toe. In each of those muscle bellies, a sesamoid bone—one that is seeded within a tendon—typically grows at the head of the first metatarsal. So, when we're standing, because of the arches present in the foot, we're really balancing our weight on the calcaneus distally, the two sesamoid bones of the great toe medially, and the heads of the other four metatarsals passing laterally. Unsurprisingly, this flexor of the big toe is supplied by the medial plantar nerve.

Laterally, in this third layer, flexor digiti minimi—to which some sources add the adjective *brevis*—originates off of the base of the fifth metatarsal and from the fibularis longus tendon that crosses the plantar foot. Flexor digiti minimi inserts on the lateral side of the base of the little toe's proximal phalanx. As its name implies, it flexes the little toe, and it does so at the MTP joint. Unsurprisingly, flexor digiti minimi is supplied by the lateral plantar nerve.

Between the two flexors in this third layer is a two-headed muscle named adductor hallucis. It has an oblique head that originates from the bases of the second through fourth metatarsals and the tendon of fibularis longus, but its transverse head comes off the MTP ligaments of some of the smaller toes. Together, both heads insert on the lateral side of the base of the proximal phalanx of the big toe. The net result is a two-headed muscle that roughly has the shape of the number seven, at least when looking at the plantar surface of a right foot.

In terms of innervation, think about what the number seven looks like upside-down—like an *L*—and the adductor hallucis is supplied by the *lateral* plantar nerve. As the name implies, the adductor hallucis draws the metatarsals together, which helps maintain the transverse arch of the foot and helps support our feet while standing so that the bones don't splay out.

In the fourth and final layer, there are two muscles—really two groups of muscles—and two tendons. The tendons are from the fibularis longus and tibialis posterior muscles. Fibularis longus is a muscle of the lateral compartment of the leg that sends its tendon across the sole of the foot from lateral to medial. The fibularis longus tendon is part of the origin for two muscles of the third layer but also helps support the arches of the foot by its insertion on the medial cuneiform bone and base of the first metatarsal. The tendon of tibialis posterior fans out on the medial plantar surface and links together several of the tarsals, including the navicular, the cuboid, all three cuneiforms, the sustentaculum tali on the calcaneus, and even several metatarsals.

The muscles of the fourth layer are the plantar and dorsal interossei. There are usually three plantar interossei; they originate from the third through fifth metatarsals and insert on the medial sides of the proximal phalanges. There are typically four dorsal interossei that originate between adjacent metatarsals and insert on the proximal phalanges.

Palmar interossei adduct the metatarsals, and dorsal interossei abduct the metatarsals. In the foot, the axis of adduction and abduction is the second toe, not the middle toe. And these aren't actions most people can perform willingly, but refer to the adduction that helps keep the toes pulled together when we're on our feet. Alternatively, abduction fans the toes out, like if stretching your foot.

Both the palmar and dorsal interossei also aid flexion of the MTP joints, and both are supplied by the lateral plantar nerve. Though the dorsal interossei can be best seen from the dorsum of the foot, deep to extensor hallucis brevis and extensor digitorum brevis, they're still considered the deepest layer of the plantar foot so as not to break innervation rules.

Reading

Biel, *Trail Guide to the Body*, ch. 7, "Leg & Foot."

Bowden and Bowden, *An Illustrated Atlas of the Skeletal Muscles*, ch. 10, "Muscles of the Lower Leg and Foot."

Jarmey, *The Concise Book of Muscles*, ch. 10, "Muscles of the Leg and Foot."

Stone and Stone, *Atlas of Skeletal Muscles*, ch. 9, "Muscles of the Leg and Foot."

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Lecture 24

DIGITAL CADAVER LESSON: THE LOWER LIMB

This is a digital lecture that reviews what has been covered in lectures 19 through 23 using the Anatomage Table to move three-dimensionally through the human body. Watch the video to look beneath the skin and aid your understanding.

Reading

Herbert, Heisler, Chinn, Krabbenhoft, and Malakhova, *A Photographic Atlas for Anatomy & Physiology*, ch. 3, “The Skeletal System”; ch. 4, “The Muscular System” (cadaver images).

Martini, *Martini’s Atlas of the Human Body*, Lower Limb sections (cadaver images).

Schünke, Schulte, and Schumacher, *Thieme Atlas of Anatomy*, ch. D, “Lower Limb.”

Ward, *Netter’s Integrated Musculoskeletal System*, ch. 11, “Clinical Anatomy of the Lower Limb.”

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Notes

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